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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1954 ANNUAL MEETING

AT

COLUMBIA UNIVERSITY

NEW YORK CITY

January 28–30, 1954

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BULLETIN

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1954 ANNUAL MEETING AT NEW YORK, NEW YORK, JANUARY 28–30, 1954

THE **1954 Annual Meeting of the American Physical Society** will be held at Columbia University, New York City, on **Thursday, Friday, and Saturday, January 28, 29, and 30, 1954.** Concurrent meetings will be held by the American Association of Physics Teachers, hereinafter to be denoted by AAPT. The ceremonial session of Friday afternoon in the McMillin Theatre and the banquet of Friday evening in the Hotel New Yorker will be shared by the two Societies.

This time we have come very near to bursting the seams of Columbia University. Heroic efforts were made at the last moment by the Chairman of the Local Committee—W. W. Havens, Jr., to whom the debt of the Society is beyond repayment and beyond measure—to find us more halls than we had ever used before: they succeeded, in spite of the further adverse fact that the examinations of the University are continuing into Friday. Our members will find traces of these efforts in the fact that three of the halls that appear in this programme have not appeared in any previous one, and the fact that one of these is pretty small. Another consequence is that the sessions for beta and gamma emitters have been assigned to Saturday: this topic has had more than its fair share of Saturdays in recent years; every attempt will be made to give it a different day for the next few years.

The foregoing remarks will perhaps attenuate the shock of the news that this will probably be our last meeting at Columbia University. The Annual Meetings of 1955 and 1956 will be held in hotels in New York City, and this policy will in all likelihood be continued. This final meeting at Columbia occurs in the Bicentennial Year of the University. In cognizance of this happy anniversary, and in commemoration of the fifty-five years during which Columbia has been our generous host, a session on Saturday morning is to be devoted to the history of physics and of the Society at the University. Messrs. Pegram, Fermi, and Rabi will speak of three periods of that history: the Secretary will add some words in gratitude for the services of the University to the Society (services which have not ended, since the general offices of the Society continué on the Columbia campus); and a plaque will be presented to the University in memory of the foundation of the Society. The plaque will eventually be fixed to the wall of Fayerweather Hall, in which building the Society was organized on May 20, 1899.

The **Retiring Presidential Address** of President Enrico Fermi is entitled "What can we learn with high-energy accelerators?" In the ceremonial session of the Friday afternoon, it is followed by the **presentation of the Oersted Medal** of the AAPT to C. N. Wall, and this by the twelfth **Richtmyer Memorial Lecture** of the AAPT, "Fields and Particles," by J. A. Wheeler. By dint of putting an undue number of sessions on other days, President Fermi's address was freed of competition with other papers, or as I should better have said, other papers were not exposed to competition with Fermi's. It was, however, necessary to schedule two sessions simultaneously with the Richtmyer Lecture, and six sessions simultaneously with the programme designed to honor Columbia University. This is deeply regretted. It is perhaps time to consider whether to extend the Annual Meeting over four days.

The **headquarters hotel** is as heretofore the New Yorker, at Eighth Avenue and 34th Street, adjacent to Pennsylvania Station. Reservations should have been made already: any remaining to be made should be sought without delay (do not fail to mention the Society in the letter of reservation).

The **registration desk** will be set up in Pupin Physics Laboratories, on the campus near the gate at 119th Street and Broadway. All members and guests are asked to register and frequently to consult the nearby bulletin boards for notice of messages. Payment of a registration fee of one dollar will be requested.

Invited papers in nuclear and cosmic-ray physics comprise two on molecular-beam experiments

(Ramsey, Zacharias); two on the neutrino (Cowan, Reines, Rustad); one on neutron-proton scattering (Powell); one on artificial meson-production (Luckey); two on cosmic-ray phenomena (Pomerantz, Cowan); one on low-energy neutron-spectroscopy (Havens); one on quantum electrodynamics (Kroll); a symposium on high-energy physics at Brookhaven and Nevis (Collins, Fowler, Serber, Lederman); a symposium on nuclear size and density-distribution (Hofstadter, Cohen, Rainwater, Townes); and a symposium on plans for new accelerators (Courant, Blewett, Livingston, White). In a field partaking of both nuclear and solid-state physics, there are three invited papers on magnetic and "cyclotron" resonance in solids (Schneider, Overhauser, Kittel). In extra-nuclear physics there are three symposia, two of the Division of Fluid Dynamics (note that one of these is to be held at the Hotel Astor) and one of the Division of Electron Physics; and invited papers in cryogenics (Dash, Boorse), solid-state physics (Bridgman), x-ray physics (Vineyard), and in a field which both electron physicists and solid-state physicists would like to claim as their own (Wolff, Hagstrum).

Nearly **three hundred contributed papers** are grouped in twenty-eight sessions. The Society owes a great debt to R. L. Serber for assuming the task of distributing the papers in theoretical physics among the four sessions that they require.

The **banquet of the two Societies** will be held in the Grand Ballroom of the Hotel New Yorker on Friday evening at seven. The after-dinner speakers will be President Grayson Kirk, of Columbia University, L. Brillouin, and S. A. Korff. The price will be $5.00. Formal attire will be welcomed though not required. Reservations should be made right away by filling out and mailing the form which appears on the inside back-cover page of this Bulletin. The tickets will be sold at the registration desk. The Society reserves the right to distribute unpaind-for and uncalled-for tickets to the first comers after three o'clock on the Friday afternoon.

The second **Oliver Ellsworth Buckley Solid-State Physics prize** will be conferred on John Bardeen at the banquet.

The **Business Meeting** of the American Physical Society will be held at nine o'clock on Friday morning in the McMillin Theatre.

The **Council of the American Physica Society** will meet at 2:45 P.M. on Thursday, January 28, in Room 313, Lou Memorial Library, Columbia University, unless contrary notice is sent to its members. Room 313 is two flights up the southwest stairs.

The **American Institute of Physics** will operate a **Placement Service Register** in Rooms 253 and 255 in Teachers College, Columbia University, at the time of this meeting. To facilitate the scheduling of interviews, employers and applicants should report to the Register immediately on arrival. Descriptions of open positions and requests for registration forms should be sent to the Institute, 57 East 55 Street, New York 22, New York.

The **Sigma Pi Sigma luncheon** will be held on Friday at 12:30 P.M. in the Columbia University Mens' Faculty Club, 400 West 117th Street. Price $1.75; tickets will be sold at the registration desk. Places may be reserved in advance by letter to Dr. Marsh W. White, Osmond Laboratory, The Pennsylvania State University, State College, Pennsylvania.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, January 22. The titles of such as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session V. The abstracts will not be published. Those who submit such papers cannot find out whether they are admitted without coming, or sending a messenger, to consult the blackboard.

Prospective meetings and deadlines of the Society are listed on page 6. The announcement of the Washington meeting is on page 5. Do not wait for summons cards: there will be no more of them, except in cases of emergency.

General Rules Relating to Papers

The time allowed for the oral presentation of a ten-minute paper is ten minutes at most. The time allowed for the oral presentation of an invited paper is stated in the Bulletin. When two or more contributed papers are submitted by the same author, or by more than one author but with the same name appearing first on the by-line, all but one are placed on the "supplementary programme." For each paper on this programme a session is indicated, at the end of which it may be offered; but the Chairman of the session is empowered to limit it to fewer than ten minutes, or to read it by title.

Instructions for the preparation of abstracts are printed on page 6. Note that the requirement that an abstract be typewritten automatically excludes the abstracts that are telegraphed. Telegraphed abstracts have been accepted for this meeting, but will not be accepted hereafter. Editing

of these is difficult, and there is too much danger of garbling.

The abstracts of this Bulletin will reappear, exactly as they now stand, in an issue of *The Physical Review* appearing after the meeting. Errata will be printed on a following page of *The Physical Review* if received not later than Monday, February 15, by Miss Ruth Bryans, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Do not add anything.

KARL K. DARROW, *Secretary*
American Physical Society,
Columbia University,
New York 22, New York

Please bring this Bulletin with you to the meeting

Preliminary Announcement of the 1954 Spring Meeting

The 1954 Spring Meeting of the American Physical Society will be held in Washington, D. C., on Thursday, Friday, and Saturday, April 29 and 30 and May 1, 1954. The hotels in which rooms have been reserved for our members are the Sheraton Park (formerly the Wardman Park) at 2660 Woodley Road, N. W.; Shoreham (2500 Calvert Street, N. W.); Roger Smith (18th at Pennsylvania Avenue, N. W.); Willard (14th and Pennsylvania Avenue, N. W.); DuPont Plaza (DuPont Circle, N. W.); and Windsor Park (2300 Connecticut Avenue, N. W.). Early reservation is strongly recommended. Try to share a twin-bed room with a colleague. Mention if you belong to the Society. The largest blocks of rooms are available at the Sheraton Park (400) and the Shoreham. The Sheraton Park will serve as headquarters, and the registration desk will be there.

Deadline for this meeting is Friday, February 19

Abstracts must be received at the office of the Society not later than that date, else they will not be accepted. Read and heed the instructions for the preparation of abstracts set forth on page 6.

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1953–1954

I. Meetings east of the Rockies

Place	*Meeting dates*	*Deadline date*
New York	January 28–30, 1954	past
Austin	February 26–27	December 30, 1953
Detroit-Ann Arbor	March 18–20	January 15, 1954
Washington	April 29–30, May 1	February 19
Minneapolis	June 28–30	April 30

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meetings until the deadline date of the previous meeting is past.

II. Meetings west of the Rockies

Seattle	July 7–10, 1954	May 5, 1954

Abstracts of contributed papers for the Seattle meeting are to be sent to J. Kaplan, University of California, Los Angeles 24, California.

RULES IMPOSED ON ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

The use of special delivery is perilous. For reasons which we do not pretend to understand, special-delivery stamps sometimes produce the inverse of the effect expected. Telegraphed abstracts will no longer be accepted.

EPITOME OF THE 1954 ANNUAL MEETING

(Personal names are those of invited speakers, except those at the ends of lines which are the names of halls.)

Thursday Morning

A. Collins, Shutt, Serber, Lederman. McMillin.
B. Theoretical physics, I (field-theory); Kroll. Pupin 428.
C. Reactions of transmutation, I. Pupin 301.
D. Wolff, Hagstrum; semiconductors. Horace Mann.
DA. Ramsey, Zacharias, C. L. Cowlan, Jr., Reines, Rustad. Schermerhorn 501.
E. Vineyard; x-rays and spectra. Pupin 329.

Thursday Afternoon

F. Chemical physics. Pupin 329.
G. Luckey; mesons, I. McMillin.
H. High-energy electrons; positrons; fission. Horace Mann.
I. Bridgman; solid-state physics, I. Schermerhorn 501.
IA. Theoretical physics, II. Pupin 301.
J. Division of Fluid Dynamics: Ludloff, Friedman, Hayes, Nagamatsu, Uberoi. Hotel Astor. North Ballroom.
JA. Reactions of transmutation, II; general nuclear physics. Pupin 428.

Friday Morning at 9:00

Business Meeting of the American Physical Society. McMillin.

Friday Morning at 10:00

K. Division of Fluid Dynamics: shock waves: Walsh, Willig, Hornig, Cotter. Pupin 428.
KA. Mesons, II. McMillin.
L. Magnetic resonance; Schneider, Overhauser, Kittel. Pupin 301.
LA. General nuclear physics. Casa Italiana.
M. Solid-state physics, II. Schermerhorn 501.
N. Dash, Boorse; cryogenics. Horace Mann.
O. Cohen, Hofstadter, Rainwater, Townes. Harkness.

Friday Afternoon

P. Joint ceremonial session: Fermi, Wall, Wheeler. McMillin.
PA. North Carolina papers. Pupin 301.
PB. Brookhaven papers. Schermerhorn 501

Friday Evening

Banquet of the American Physical Society and the AAPT. Grand Ballroom, Hotel New Yorker. President Grayson Kirk of Columbia, Brillouin and Korff; Buckley Prize Award.

Saturday Morning

Q. Session in honor of Columbia: Pegram, Fermi, Rabi, Darrow; presentation of a plaque. McMillin.
QA. Luminescence; electron physics. Pupin 301.
R. Beta and gamma emitters, I. Horace Mann.
RA. Magnetism. Havemeyer 309.
S. Fluid dynamics (including Business Meeting of Division of Fluid Dynamics). Pupin 428.
T. Nucleonic scattering; Powell. Schermerhorn 501.
U. Theoretical physics, III. Casa Italiana.

Saturday Afternoon

V. Microwave spectroscopy; post-deadline papers, if any. Pupin 428.
W. Division of Electron Physics: oxide-coated cathodes; Sproull, Hensley, Rittner, van der Ziel; Business Meeting of the Division. Horace Mann.
WA. Havens; neutron physics. Pupin 301.
X. Courant, Blewett, Livingston, White. Casa Italiana.
XA. Theoretical physics, IV. Schermerhorn 501.
Y. Beta and gamma emitters, II. Havemeyer 309.
Z. Pomerantz, E. W. Cowan; cosmic rays and diverse particles. McMillin.

PROGRAMME

THURSDAY MORNING AT 10:00

McMillin Theatre

(L. J. HAWORTH presiding)

Brookhaven-Nevis Symposium

A1. The Cosmotron as a Research Tool. G. B. COLLINS, *Brookhaven National Laboratory.* (30 min.)
A2. Heavy Unstable Particles and Multiple Meson Production Observed in a Cloud Chamber at the Cosmotron. R. P. SHUTT, *Brookhaven National Laboratory.* (30 min.)
A3. Interpretation of High-Energy Experiments. R. L. SERBER, *Columbia University.* (30 min.)
A4. Meson Reactions in Hydrogen. L. M. LEDERMAN, *Columbia University.* (30 min.)

THURSDAY MORNING AT 10:00

Pupin 428

(A. PAIS presiding)

Theoretical Physics, I (Field-Theory)

B1. Renormalization Questions in Curved Spaces. M. DRESDEN AND MARTIN GUTZWILLER, *University of Kansas.*—It has been investigated whether the renormalization procedures for field theories need modifications when a space of constant curvature rather than the flat space of special relativity is used. The field equations described previously[1] may be quantized simplest by observing that the commutator for the field quantities is directly related to the "elementary solution" of Hadamard of the field equations. This commutator (the analog of the Schwinger D function) is given by $D(s^2)=(1/R^2)\delta[sh^2(s/R)]+W(s^2)$ here s is the geodesic distance between two points, R is the radius of curvature, W is a hypergeometric function. It can be shown that the field equations and the commutation rules may be obtained from an appropriate modification of the Schwinger action principle.[2] An interesting difference as compared with the flat case arises from the circumstance that the solutions of the field equations do not allow an unambiguous splitting in positive and negative frequencies for all time. This complicates the Feynman type interpretation of the theory, although some of the formal relations of Feynman may be obtained directly from the Hadamard propagation formula.

[1] M. Gutzwiller, Phys. Rev. **91**, 478 (1953).
[2] J. Schwinger, Phys. Rev. **82**, 914 (1951).

B2. Avoiding Perturbation Methods in Quantum Electrodynamics, Meson Theory, Etc. F. J. BELINFANTE, *Purdue University.*—The radial function in an H atom cannot be obtained by perturbation calculus starting from a free-electron $j_l(kr)$ function. Similarly, solution of problems on bosons surrounding a fermion may require rigorous solution of a radial problem for wave functions depending on relative position of fermion and bosons. In 1932, V. Fock developed a representation "in configuration space" for finite numbers of B.E. as well as F.D. particles. Recently I discussed how positon theory can be reformulated avoiding the hole concept by means of a somewhat generalized Fock-type theory.[1] It is simple to develop theories for photons and for mesons along these lines. This enables us to write the "radial problem" for stationary states of interacting bosons and fermions, as an infinite set of simultaneous integral equations, corresponding to an expansion in numbers of particles present. Introducing the vacuum solution, one should solve for the energy difference of actual and vacuum states, for instance by relating the actual to the vacuum state vector. In complicated problems one might possibly neglect most many-particle contributions to the state vector.

[1] F. J. Belinfante, Bull. Am. Phys. Soc. (Chicago meeting) **28**, No. 6 (1953), abstract T5.

B3. "Dressed" Particles in Quantum Field Theory.* JAMES L. ANDERSON, *University of Maryland.*—In time dependent perturbation theory there exists a certain ambiguity in the breaking up of the Hamiltonian into two parts, one of which is to be considered as the perturbation. If one breaks the Hamiltonian into the two parts H_o and H_I and calls H_I the perturbing part, then it would appear equally justified to break it into two other parts H_o' and H_I', where $H_o'=(H_o+K)$, $(H_I'=H_o-K)$, and to call H_I' the perturbation. Since now the eigenstates of H_o' are employed in the specification of initial and final conditions in the theory, one might determine H_o' (or K) by requiring that it describe properly the "dressed" particles of the theory. This means that H_o' must be so chosen that

$$\langle\Psi_o,\ T[\bar{\psi}(x)\psi(y)]\Psi_o\rangle=\langle\Phi_o,\ T[\bar{\psi}(x)\psi(y)]\Phi_o\rangle,$$

where Ψ_o is the vacuum state of the interacting system, Φ_o the lowest energy state of H_o', $\bar{\psi}(x)$ and $\psi(y)$ are Heisenberg operators, and $\bar{\psi}(x)$ and $\psi(x)$ are operators in an interaction representation defined by H_o'. The existence of an H_o' satisfying this condition and its relation to the renormalization program will be discussed.

* Supported by the U. S. Office of Naval Research.

B4. Meson Nucleon Scattering. I. R. J. RIDDELL, JR., AND BURTON D. FRIED, *University of California, Berkeley.*—The problem of meson scattering from a fixed nucleon has been investigated for intermediate values of the coupling constant g. The nonrelativistic one-body problem (i.e., one real, fixed nucleon and no real mesons) can be treated by a variational procedure due to Tomonaga which is correct in both the weak and strong coupling limits. In the same spirit, we have tried

to find a consistent method of calculating the scattering cross section which is correct in *both* limiting cases and which leads to feasible numerical calculations for intermediate values of g. To find the wave function of the scattered meson, we use the matrix equations of motion in an energy representation. This leads to an infinite system of coupled equations which can be reduced to a finite set by the approximation of neglecting all states containing more than one *real* meson. It is to be emphasized that this implies *no* restriction on the *total* number of mesons present, since we allow the nucleon to be surrounded by any number of bound, virtual mesons. This is in contrast to the Tamm-Dancoff approximation which limits the total number of mesons present and which consequently cannot give the correct strong coupling limit.

B5. Meson Nucleon Scattering. II. BURTON D. FRIED AND R. J. RIDDELL, JR., *University of California, Berkeley.*—To illustrate the method described in the preceding abstract, we apply it to the charged scalar meson field. Let $|Q, p_1 \cdots q_m)$ denote an exact energy eigenstate of charge Q in which there are asymptotically n positive mesons of momenta $p_1 \cdots p_n$ and m negative mesons of momenta $q_1 \cdots q_m$. The wave function of a positive meson incident with momentum p on a proton is then $(1|A|2p)$ where A is the annihilation operator for positive mesons. To find this matrix element from the equations of motion we need terms like $(1|A\tau_3|2p)$. These we evaluate by matrix multiplication, neglecting all intermediate states with more than one real meson and making the further approximation that $(2p'|\tau_3|2p)=(1|\tau_3|1)\delta(p-p')$, etc. Finally, one-body matrix elements like $(1|\tau_3|1)$ are evaluated by using for $|Q)$ the corresponding Tomonaga state vector. The resulting equations can be solved analytically in both the weak and strong coupling limits, giving cross sections which agree with perturbation theory and strong coupling theory, respectively. For intermediate coupling, numerical computations have been carried out and curves of cross section *vs* meson energy will be presented. It may be noted that the approach described here also gives the correct strong coupling isobar separation.

B6. Effect of Negative Energy Components in the Two-Nucleon System. R. ARNOWITT AND S. GASIOROWICZ, *University of California, Berkeley.*—A feature of the Levy-Klein solution of the Bethe-Salpeter equation for the deuteron is the elimination of ϕ_{+-}, ϕ_{-+}, and ϕ_{--} in terms of the ϕ_{++} component of the wave function via a perturbation expansion. To investigate the validity of this procedure, the coupled equations for the various components in the first nonadiabatic approximation to the Δ_+ interaction were examined. A set of first-order radial equations with multiplicative potentials (in the region $r>1/m$) was obtained, involving $\phi_{\pm\pm}(r)=\frac{1}{4}(1\pm\beta_1)(1\pm\beta_2)\phi(r)$. A rigorous elimination of ϕ_{+-} and ϕ_{-+} led to equations containing ϕ_{++} and ϕ_{--}. In addition to velocity dependent terms, potentials of the type

$$\frac{\mu^2}{2m}\frac{g^2}{4\pi}\tau_1\cdot\tau_2\frac{Y(r)}{P_0+\frac{1}{2}\dfrac{g^2}{4\pi}\tau_1\cdot\tau_2 Y(r)}$$

appear. Expanding the denominator yields the usual Yukawa second-order potential plus a term proportional to $g^4(\tau_1\cdot\tau_2)^2$. Such an expansion however is poor even for $r\sim 1/\mu$, a pole actually existing near $r\sim 0.7/\mu$ for the charge singlet state. Thus the perturbation expansion appears to alter radically the structure of the equations.

B7. Interaction Between Two Nucleons.* BEHRAM KURŞUNOĞLU, *Cornell University.*—A three-dimensional equation for two interacting nucleons can be obtained from the covariant Bethe-Salpeter equation which is identical with the one derived recently by Dyson[1] through the introduction of a new Tamm-Dancoff amplitude that takes correct account of the interacting vacuum state. The energy denominators for the positive-energy projected components of the wave function in G^2 order charge-symmetric $ps-ps$ theory is the same as in the old T.D. method. In the G^4 order interaction the no-pair terms agree with the T.D. method, but in the one-pair and two-pair terms the signs of the intermediate energies in the denominators appear in accordance with the particle and antiparticle description. The resulting adiabatic nuclear forces is being investigated. The renormalizations of mass and charge to any order do not present any formal difficulty.

* Supported by the Turkish Government and U. S. Office of Naval Research.

[1] F. J. Dyson, Phys. Rev. **91**, 1543 (1953).

B8. Low Energy Limits of Meson Processes. S. DESER AND W. E. THIRRING, *Institute for Advanced Study,* AND M. L. GOLDBERGER, *Princeton University.*—It is well known that the perturbation-theoretical matrix element for meson-nucleon scattering is finite at zero energy. A similar result holds for the threshold photo-production of charged mesons. It has been shown by Kroll and Ruderman,[1] on the basis of a particular renormalization scheme, that at threshold, the exact photoproduction matrix element reduces to the perturbation-theoretic result with renormalized coupling constant in the limit of zero meson mass. There is, however, some arbitrariness in mesic charge renormalization. We have developed a new computational technique which permits an exact evaluation of the meson-nucleon scattering matrix in the limit of zero energy and zero meson mass. By a suitable choice of renormalization it reduces to the perturbation-theoretic value with renormalized coupling constant and nucleon mass. In the new scheme, the photoproduction theorem no longer holds nor do the two definitions of g bear any close relation. Using the fact that the isotopic spin dependence occurs with odd powers of μ/M,[2] dropping terms higher than the first, our coupling constant may be computed from the two s-wave scattering lengths. Using Fermi's latest data (unpublished) we find $g^2/4\pi=0.36$. The possible significance of this result will be discussed.

[1] N. Kroll and M. Ruderman, Phys. Rev. (to be published).
[2] M. Gell-Mann and M. L. Goldberger (private communication).

B9. Classical Theory of High-Energy Processes. M. A. RUDERMAN, *University of California, Berkeley,* AND H. BROWN, *University of California, Livermore.*—In the classical limit ($h\to 0$) there exists a nondivergent pseudoscalar meson theory with gradient coupling. Infinities can be renormalized in terms of the experimental nucleon mass and the moment of inertia associated with changing the nucleon spin direction.[1,2] The high-energy collisions of two such nucleons have been investigated. Results will be reported for the cross section and spectrum of meson emission and their dependence upon coupling constant and moment of inertia.

[1] H. J. Bhabha, Proc. Roy. Soc. (London) **A178**, 314 (1941).
[2] H. J. Bhabha and H. C. Corben, Proc. Roy. Soc. (London) **A178**, 273 (1941).

B10. Quantized Interaction of Relativistic Fields. HANS FREISTADT, *Newark College of Engineering.*—An attempt is made to describe observed quantum effects by a classical relativistic field theory. The procedure followed by Bohm[1] for particle physics does not suggest any general method of finding classical equations which describe quantum effects (a modified Hamilton-Jacobi equation and the equation of continuity) except by recourse to the usual formulation of quantum theory. To circumvent this difficulty, it is suggested that only the interaction between fields exhibits quantum effects, the free fields remaining unquantized. A Hamilton-Jacobi equation for interacting relativistic fields is developed, a very simple extension of which yields the equations of the usual

interaction representation of quantum electrodynamics. The method is applicable to any theory of interacting fields, but it remains to be seen whether physically meaningful results are obtained in cases other than that of interacting electromagnetic and spinor fields.

[1] D. Bohm, Phys. Rev. **85**, 166, 180 (1952).

B11. Collision Matrix for Dirac Particles.* BRUNO ZUMINO, *New York University.*—The collision matrix for a quantized Dirac field in an external electromagnetic potential is calculated by a method different from the commonly used Feynman technique. Our method may supply a basis for a more rigorous mathematical justification of the results. First the collision matrix for the unquantised Dirac field is obtained from the solution of an integral equation. The collision matrix for the field quantized in the sense of the theory of positrons can be then derived in an exponential form which shows clearly that the matrix is unitary. The creation and annihilation operators are now separated by means of a method due to Friedrichs, which uses a theorem by Baker and Hausdorff on exponentials of noncommuting quantities. One obtains the collision matrix expressed as a product of exponentials, involving creation and annihilation operators in a way suitable for the calculation of matrix elements in the configuration space of the electrons. It is possible to show that the matrix-elements obtained by this method are the same as those calculated by use of Feynman graphs.

* Supported by the U. S. Office of Naval Research.

Invited Paper

B12. Survey of Quantum Electrodynamics. N. M. KROLL, *Columbia University.* (40 min.)

THURSDAY MORNING AT 10:00

Pupin 301

(W. W. BUECHNER presiding)

Reactions of Transmutation, I

C1. Energy Dependence of Coulomb Excitation of Ta and Au.* W. I. GOLDBURG AND R. M. WILLIAMSON, *Duke University.*—Low-lying levels in Ta and Au were excited by means of the Coulomb excitation process[1,2] using 2- to 4-Mev protons from the Duke Van de Graaff accelerator. Gamma yields at 90° to the incident protons were taken with a NaI scintillator and a single-channel pulse-height analyzer. Thick target yields of 135-kev and 290-kev gammas from Ta, normalized to the theoretical yields[3] at 2-Mev proton energy, were found to increase to 25 percent above the calculated yields at 4 Mev. The cascade 155-kev gamma was also partially resolved. Both thick and thin target data taken on the gold 280-kev gamma gave an experimental cross section the slope of which was 30 percent in excess of the theoretical slope between 2.5 and 4 Mev. A 550-kev gamma behaved similarly between 3.5 and 4.25 Mev.

* Work supported by the U. S. Atomic Energy Commission.

[1] T. Huus and Č. Zupančič, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **28**, 1 (1953).
[2] C. L. McClelland and C. Goodman, Phys. Rev. **91**, 760 (1953).
[3] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).

C2. Coulomb Excitation of Heavy and Medium Nuclei by Alpha Particles. G. M. TEMMER AND N. P. HEYDENBURG, *Department of Terrestrial Magnetism.*—We have investigated the Coulomb excitation of the low-lying levels of some 30 nuclei between $Z=20$ and $Z=90$ with our electrostatic generator and a NaI crystal spectrometer. Because of their higher charge and lower velocity at a given energy, alpha particles satisfy the condition $(2Z_1Z_2e^2/\hbar v)\gg 1$ down to $Z\sim 20$, hence allowing the application of the simplified theory[1] of the excitation process. We have studied Ta^{181} and Mn^{55} in detail, obtaining thick target alpha excitation curves between 1.00 and 3.80 Mev for the 137-kev γ ray and K x-ray of Ta and the 128-kev γ ray of Mn, the energy dependence being in good agreement with theory.[1] We have also measured proton excitation of Ta^{3} over the same energy interval. At 3 Mev the ratio of K to gamma excitation is 2.27 for alphas and 14.8 for protons, illustrating the relative advantage of aphas for the heavy elements. Gamma background for the lighter elements under proton bombardment is prohibitive whereas it is quite negligible for alphas. In most nuclei investigated we find the low-lying excited states as known from beta and gamma spectroscopy, ranging in energy from 50 kev (Th^{232}) to 440 kev (Se^{77}). A table of the observed transitions and their approximate relative intensities will be presented. The importance of light element target impurities will be discussed.

[1] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).
[2] T. Huus and Č. Zupančič, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953); C. McClelland and C. Goodman, Phys. Rev. **91**, 760 (1953).

C3. Coulomb Excitation of Heavy Nuclei. C. M. CLASS, C. F. COOK AND J. T. EISINGER, *Rice Institute* (received by wire).—Supported in part by U. S. Atomic Energy Commission stop Gamma rays believed to be due to nuclear coulomb excitation footnote one were observed when TA, W, AU, and PT targets were bombarded with three Mev protons stop The intense K x-rays were suppressed by using appropriate absorbers stop The target and accelerator background was negligible stop The radiation was detected with a sodium iodide counter having a resolution of ten percent stop Energies assigned to the well resolved gamma rays are colon TA comma 139 comma 167 and 309 kev semicolon PT comma 212 comma 240 and 33 kev semicolon AU comma 1.73 Mev and W comma 450 kev comma with errors of 5 kev stop Additional lines from PT comma AU and W are poorly resolved stop The measurement of yield curves and the use of selective absorbers for the three TA lines indicate that the 167 kev line is due to a cascade gamma ray between the 309 kevs and 139 kev leves. The relative intensities of the lines allow a better determination of the cross-over transition probability than heretofore possible. The angular distribution of the 139 kev and 309 kev radiations from tantalum has been measured. The former is isotropic while the latter distribution fits one plus .23 cosine squared theta in agreement with the theory. Footnote two.

Paragraph. Footnote one. T. Huss and C. Zupancic, Kglo Danske Videnskaboselskab, Mat.-fys. Medd. **28**, No. 1 (1953); C. McClelland and C. Goodman, Phys. Rev. **91**, 760 (1953) Footnote two. K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).

C4. Angular Distribution of Alpha-Particles from (p,α) Reactions. E. NEWMAN AND W. L. ALFORD,* *Oak Ridge National Laboratory.*—Using the internal, 22-Mev proton beam of the Oak Ridge National Laboratories 86-inch cyclotron, the angular distribution of alpha particles resulting from (p,α) reactions on several elements have been studied. The detectors consisted of a thin layer (approximately 5 mg/cm²) of $ALPO_4$ sprayed on an aluminum backing and utilized the activation detection[1] reaction $P^{31}(\alpha,n)Cl^{34}$. The chlorine was separated chemically and counted under end-window Geiger counters. Separate runs were made to establish the adequacy of the chemistry and to prove the effect of impurities in the aluminum phosphate to be negligible. Absorption tests performed at various angles demonstrated the validity of the method for detecting the desired angular distributions. Data were obtained from 15° to 170° with respect to the incident proton beam. Since the observed angular distributions are strongly peaked in the forward direction this may indicate the process to be one of direct interaction rather than compound nucleus formation.

* Research participant from Alabama Polytechnic Institute.
[1] B. L. Cohen and R. V. Neidigh, Rev. Sci. Instr. (to be published).

C5. Gamma Rays from the Inelastic Scattering of Alpha Particles by Lithium and Fluorine. N. P. HEYDENBURG AND G. M. TEMMER, *Department of Terrestrial Magnetism.*—We have observed the 478-kev gamma ray, excited by inelastic scattering of alpha particles from lithium, with a NaI crystal spectrometer. A thin target yield curve showed resonances, corresponding to energy levels in the compound nucleus B^{11}, at the following bombarding energies: 1.91, 2.46, 2.60, 2.70, 2.81, and 3.06 Mev. A search for alpha- capture gamma-ray resonances up to 2.5 Mev revealed none above the known resonances at 820 and 960 kev. The bombardment of a thin CaF_2 target by alpha particles gave three gamma-ray lines at 108 ± 2, 196 ± 2, and 1280 kev. The NaI spectrometer was calibrated with the 68- and 142-kev lines of Th^{230}, the 190-kev line of In^{114} and the 1.28-Mev line of Na^{22}. The first two gamma lines are due to the inelastic excitation of the first two excited states of F^{19}. The 1.28-Mev line is due to the excitation of the 1.28 level in Ne^{22} by the reaction $F^{19}(\alpha,p\gamma)Ne^{22}$. A yield curve for the 108- and 196-kev lines gave resonances at alpha energies: 2.48, 2.55, 2.64, 2.77, 2.90, 3.02, 3.05, 3.18, and 3.34 Mev, corresponding to levels in the compound nucleus Na^{23}. There is evidence for Coulomb excitation of the 196-kev level below 2.2 Mev.

C6. Alpha-Neutron Reactions in Be^9, B^{11}, and C^{13}. R. E. TRUMBLE, JR.,* *Catholic University of America, and Department of Terrestrial Magnetism.*—The neutron yields from thin targets of Be^9, B^{11}, and C^{13} (23 percent) bombarded by alpha particles have been observed for alpha-particle energies between 1.0 and 3.5 Mev. B^{10} and C^{12} thick targets were found to give negligible neutron yield for B^{10} and no detectable yield for C^{12}. A paraffin-imbedded BF_3 "long counter" subtending a 60° cone at the target was used to detect neutrons whose mean directions made angles of 0° and 90° with the direction of the incident alpha particles. Several neutron resonances were found to have marked angle dependence. Strong resonances were found at 1.91, 2.24, 2.58, and 3.40 Mev for Be^9; at 1.54, 2.09, 2.63, 3.00, and 3.26 Mev for B^{11}; and at 2.44, 2.66, 2.76, and 3.30 Mev for C^{13}. Numerous weaker resonances were observed for each of these targets. Neutron yield curves for Be^9, B^{11}, and C^{13} and calculated energy levels in C^{13}, N^{15}, and O^{17} will be shown.

* United States Naval Academy, Annapolis, Maryland.

C7. Energies of Excited States of Be^{10}. C. K. BOCKELMAN AND J. J. JUNG,* *M.I.T.*—Thin targets of beryllium evaporated on a Formvar backing were bombarded by deuterons accelerated in the MIT–ONR electrostatic generator.† A magnetic spectrograph, calibrated with polonium alpha particles, was employed to obtain the momentum spectrum of protons emitted at 90 degrees to the incident beam. Measurements made at several deuteron energies between 5.4 and 7.6 Mev permitted identification of the target nucleus involved. The ground-state Q value for $Be^9(d,p)Be^{10}$ and the position of excited states at 3.37, 7.37, and 7.54 Mev agree with previous measurements.[1] The reported 6.2-Mev level was found to consist of states at 5.96 and 6.26 Mev. A summary of previous experimental results may be found in reference 1.

* On leave from the University of Strasbourg, Strasbourg, France.
† This work has been supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

C8. Energy Levels from the Reaction $B^{10}(\alpha,p)C^{13}$. W. J. FADER AND A. SPERDUTO, *M.I.T.*—Levels in the C^{13} nucleus have been studied by the $B^{10}(\alpha,p)C^{13}$ reaction with the MIT–ONR electrostatic generator.* The region of excitation from the ground state to 4.7 Mev was covered using singly charged helium ions with incident energies of 4.8 and 5.8 Mev. Three excited states in C^{13} were found with energies of 3.09, 3.68, and 3.85 Mev, which values are in good agreement with the $C^{12}(d,p)C^{13}$ results.[1] No evidence has been found for proton groups which would correspond to the 0.7 and 4.6 levels previously reported from $B^{10}(\alpha,p)C^{13}$.

* This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

C9. Differential Cross Sections for the $C^{13}(d,t)C^{12}$ Reaction.* H. D. HOLMGREN, J. M. BLAIR, B. E. SIMMONS, AND R. V. STUART, *University of Minnesota.*—The differential cross sections for the $C^{12}(d,t)C^{13}$ pickup reaction[1] have been measured at laboratory energies of 2.19 Mev and 3.29 Mev for thirteen center-of-mass angles extending from 17° to 144°. The tritons were separated from the scattered deuterons and the other reaction products by a combination of magnetic analysis and range measurements in nuclear emulsions. The targets were prepared by cracking C^{13}-enriched methyl iodide onto 0.005-mil Ni foils. The center-of-mass differential cross section at 3.29 Mev decreases from 34 mb/sterad at 17° to a minimum of 3.0 mb/sterad near 60°; then increases to 4.5 mb/sterad at 80° and remains approximately constant out to 144°. At 2.19 Mev the behavior of the differential cross section is similar, decreasing from 23 mb/sterad at 17° to 4.0 mb/sterad in the neighborhood of 70°, then rising to 6.0 mb/sterad at 100°.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).

C10. Excitation Functions for Nitrogen Induced Nuclear Reactions in Carbon. A. ZUCKER AND H. L. REYNOLDS, *Oak Ridge National Laboratory.*—Nuclear reactions produced by high-energy nitrogen ions on carbon have been observed previously.[1] With the 28-Mev deflected nitrogen beam of the Oak Ridge National Laboratory 63-inch Cyclotron the absolute cross sections for the reactions $C^{12}(N^{14})F^{18}Be^8$, $C^{12}(N^{14})Na^{24}2H^1$, and $C^{12}(N^{14})Na^{22}He^4$ have been determined as a function of incident beam energy. An eight-position target holder was rotated rapidly through the collimated external beam. In seven of its positions were located carbon disks together with suitable nickel foil absorbers, while the eighth position was used to measure beam current. The nickel absorbers varied the incident energy between 16 and 28 Mev. The cross sections were determined by β counting of the produced radioactive nuclei with a calibrated end-window Geiger counter. The total yield curves, obtained in this way, were differentiated to give excitation functions. At 24 Mev the cross section for both reactions $C^{12}(N^{14})F^{18}Be^8$ and $C^{12}(N^{14})Na^{24}2H^1$ is of the order of $2\cdot10^{-26}$ cm². Above this energy the reaction

$C^{13}(N^{14})F^{18}Be^{8}$ becomes more probable, while at lower energies the cross section for $C^{13}(N^{14})Na^{24}2H^{1}$ is the larger one. For example at 18 Mev the cross section for $C^{13}(N^{14})Na^{24}2H^{1}$ is approximately six times the cross section for $C^{12}(N^{14})F^{18}Be^{8}$.

[1] Reynolds, Scott, and Zucker, Proc. Natl. Acad. Sci. U. S. **39**, 975 (1953).

C11. Energy Levels of Al^{27}. S. F. ZIMMERMAN, JR., AND C. P. BROWNE, *M.I.T.*—The nuclear-energy levels of Al^{27} up to an excitation of 5.9 Mev have been investigated through inelastic proton scattering.* Protons accelerated to energies of 5 to 8 Mev by the MIT–ONR electrostatic generator bombarded targets of thin foil on a thin layer of aluminum evaporated onto Formvar. The energies of protons scattered at 90 degrees were measured with the annular magnetic spectrograph. Of the proton groups observed, twenty-four have been assigned to Al^{27}. The general picture of the previously published[1] spectrum is confirmed. However, in two cases, the previous groups have been resolved to show two closely spaced levels. One pair occurs at 3.0 Mev and another at 5.4 Mev. In general, the level positions disagree by amounts increasing with excitation up to as much as 70 kev.

* This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Reilley, Allen, Arthur, Bender, Ely, and Hausman, Phys. Rev. **86**, 857 (1952).

C12. Gamma-Ray Energies from Al^{27} and S^{32}.* J. A. SMITH, J. N. COOPER, AND J. C. HARRIS, *Ohio State University.*—A scintillation spectrometer has been used to measure energies of gamma rays present at nine resonances in the reaction $Mg^{26}(p, \gamma)Al^{27}$, and at five resonances in the reaction $P^{31}(p, \gamma)S^{32}$. All resonances are in the range 400-kev to 1200-kev proton energy. The gamma-ray energies observed in both reactions were consistent with the intermediate level schemes for the respective product nuclei, as determined by the Pittsburgh group[1,2] by $p-p$ scattering (although not all intermediate levels seemed to be involved in the decays).

* This research was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Reilley, Allen, Arthur, Bender, Ely, and Hausman, Phys. Rev. **86**, 857 (1952).
[2] Arthur, Allen, Bender, Hausman, McDole, Diana, Rhodes, and Barjon, Phys. Rev. **87**, 237 (1952).

C13. Angular Distribution of Gamma Rays from $Al^{27}(p\gamma)Si^{28}$. H. E. GOVE, E. B. PAUL, G. A. BARTHOLOMEW, AND A. E. LITHERLAND, *Chalk River Laboratories.*—The Chalk River electrostatic generator has been used to investigate the reaction $Al^{27}(p\gamma)Si^{28}$. The high-energy proton-capture γ rays were detected in a 2-inch diameter by 2-inch long NaI crystal and a Dumont 6292 photomultiplier. Gamma rays below 2 Mev were detected in a 1-inch diameter by 1-inch long NaI crystal. The high-energy γ-ray spectrum has been studied at 48 resonances in the range of proton energies from 0.65 to 2.2 Mev. The angular distributions of the capture γ ray to the first excited state of Si^{28} have been obtained at 17 of these resonances. The angular distribution of the ground-state γ ray has been measured at one resonance, and in a few cases the angular distribution of γ rays to higher states was measured. The angular distribution obtained at the 0.65 Mev resonance for the γ ray to the first excited state agrees with the result previously obtained by Rutherglen.[1] All angular distributions measured were symmetric about 90°. In a few cases a definite spin and parity assignment can be made from the angular distributions.

[1] J. G. Rutherglen (private communication).

C14. Partial Widths for the Reactions $Al^{27}(p\gamma)Si^{28}$ and $Al^{27}(pp')Al^{27}$*. E. B. PAUL, H. E. GOVE, G. A. BARTHOLOMEW, AND A. E. LITHERLAND, *Chalk River Laboratories.*—The apparatus described in the previous abstract has been used to measure the absolute yields for the capture γ rays leading to the first excited state of Si^{28}, and for the γ rays (0.84 and 1.05 Mev) following inelastic scattering of protons in Al^{27} at 25 of the 48 resonances. In a few cases, the γ ray following the (p,α) reaction leading to the first excited state of Mg^{24} at 1.38 Mev has also been measured. Partial widths for capture γ rays leading to the first excited state of Si^{28} lie in the range from 0.2 to 2.0 ev while those for $(pp'\gamma)$ reactions, in the region of $E_p = 2.0$ Mev, are about 10 ev with a few as high as 60 ev. The $(p\alpha\gamma)$ widths are similar to the $(pp'\gamma)$ widths. In the region where the total radiation width has been measured[1] the ratio of the partial width for the γ ray to the first excited state to the total radiation width is about 0.2.

[1] Bostrom, Huus, and Tangen, Phys. Rev. **71**, 661 (1947).

THURSDAY MORNING AT 10:00

Horace Mann

(G. L. PEARSON presiding)

Invited Papers

D1. Theory of the Energy Distribution of Secondary Electrons. P. A. WOLFF, *Bell Telephone Laboratories.* (30 min.)

D2. Theory Concerning Secondary Electrons Ejected from Metals by Ions. H. D. HAGSTRUM, *Bell Telephone Laboratories.* (30 min.)

Semiconductors

D3. The Germanium-Oxygen System.* MICHAEL HOCH AND HERRICK L. JOHNSTON, *The Ohio State University.*—The high-temperature x-ray diffraction patterns of germanium plus germanium oxide, GeO_2, between 750° and 1400°C showed that germanium monoxide, GeO, is not a stable compound. At elevated temperatures germanium can dissolve up to 60 atom percent of oxygen. The oxygen causes a very slight expansion of the germanium lattice. At 850° and 930°C, the x-ray pattern of a germanium-oxygen compound, consisting of equimolecular quantities of germanium and oxygen, showed only the germanium pattern. At 1000° and higher (above the melting point of pure germanium, 965°C), the germanium pattern disappears, and a liquid-like structure is visible, though the sample is still solid (melting point 1430°C). When the temperature is lowered again to 930°C, the germanium pattern reappears. The electrical resistivity shows a sharp break at 970°C. Thus we have a disordering of the germanium lattice, in the germanium-oxygen compound above the melting point of pure germanium.

* Supported in part by the U. S. Office of Naval Research.

D4. Electrical Properties of Dislocations in Plastically Deformed Germanium. G. L. PEARSON, W. T. READ, JR., AND F. J. MORIN, *Bell Telephone Laboratories.*—Measurements of conductivity, Hall effect, and lifetime were made on rods of both *p*- and *n*-type germanium which had been bent plastically while heated by passing current through them.[1] Deformation had no measurable effect of either conductivity or Hall mobility in 15-ohm cm *p*-type germanium. Deformation reduced both mobility and carrier density in 15-ohm cm *n*-type germanium. Plots of mobility and carrier density *vs* temperature indicate that deformation introduces acceptor-type electronic energy levels lying in the middle or upper half of the energy gap. These levels are believed to be associated with dangling, unpaired electrons on edge dislocations, which accept other electrons to make a dangling pair as discussed by Shockley.[2] As the dislocation accepts electrons, it becomes a negatively charged line surrounded by a cylindrical region of fixed positive space charge. The energy per added electron on the dislocation is increased by the increase in potential in the space charge region. The variation of average carrier density with temperature is consistent with a single energy level about 0.2 ev below the conduction band and a density of dislocations 2 to 3 times the minimum, about 10^7 per cm^2, calculated from the radius of curvature.

[1] Pearson, Read, and Morin, Phys. Rev. (to be published).
[2] W. Shockley, Phys. Rev. **91**, 228 (1953).

D5. Mobility of Impurity Ions in Ge and Si. J. C. SEVERIENS* AND C. S. FULLER, *Bell Telephone Laboratories.*—It is of interest to investigate the mobilities of impurity elements in Ge and Si in order to secure information on their state of ionization and to provide, also, independent and more accurate measures of their diffusivities. By diffusing hemispherical *n*-type regions of Li into Ge and Si and applying dc fields of 1–10 volts, we have determined Li^+ mobilities in the range 150–850°C. The drift times varies from 5 min to 3 hours and the drift distances ranged from 3 to 25 mils. The diffusivities D calculated from the Einstein relation, $D=\mu kT/q$, where μ is the ion mobility in cm^2 per volt sec are given by $D=22\times10^{-4}\exp(-11600/RT)$ and $D=61\times10^{-4}\exp(-16600/RT)$, for Li in Ge and Si, respectively. These equations agree with those previously published[1] and show that Li^+ follows the Einstein relation in this concentration range. The same method applied to Cu in Ge showed a drift of 4 mils in 45 sec toward the negative electrode for a field of 1 volt/cm. The magnitude of the diffusivity of Cu in Ge calculated from these data agrees within error with that previously observed.[2]

* Present address: Johns Hopkins University.
[1] C. S. Fuller and J. A. Ditzenberger, Phys. Rev. **91**, 193 (1953).
[2] C. S. Fuller and J. D. Struthers, Phys. Rev. **87**, 526 (1952).

D6. Volume and Surface Recombination Rates in Germanium. J. P. MCKELVEY AND R. L. LONGINI, *Westinghouse Research Laboratories.*—Bulk minority carrier lifetimes and surface recombination rates have been studied using apparatus similar to that of Navon, Bray, and Fan.[1] Diffusion theory for carriers of bulk lifetime τ has been utilized, considering a definite nonrecombination probability, or reflection coefficient, to be associated with the surface, to examine the roles of bulk and surface recombination effects, and to derive a relationship between the surface reflection coefficient and the surface recombination velocity. If the surface recombination velocity is known, the effective recombination cross section per unit surface area can be calculated. Experimental methods of separating bulk and surface effects have been devised, and values of bulk lifetime and surface recombination velocity have been measured for both *n*- and *p*-type germanium, and for a variety of surface treatments. The "WAg" surface etch,[2] which etches preferentially along (111) planes, is found to produce the lowest observed values of surface recombination velocity, 30 cm/sec for *n* type and 160 cm/sec for *p* type germanium. It is shown also that by modifying the experimental technique, the experimental apparatus can be used to measure drift mobility of minority carriers.

[1] Navon, Bray, and Fan, Proc. Inst. Radio Engrs. **40**, 1342 (1952).
[2] R. H. Wynne and C. Goldberg, J. Metals **5**, 436 (1953).

D7. Interstitial Ge in Heat Treated Germanium. SUMNER MAYBURG, *Sylvania Electric Products, Inc.*—A special heat treatment consisting of joule heating in good vacuum has allowed the study of lattice defects in germanium by low-temperature (195°K) resistivity measurements. This heat treatment technique is required in order to prevent contamination of the germanium with impurities such as copper which contribute to the electrical conductivity. By heating the germanium over 850°C and by quenching by radiation cooling, we are able to introduce of the order of 10^{14} acceptors per cc. If the sample is now annealed at a temperature in the neighborhood of 600°C, the concentration of acceptors drops rapidly with annealing time. However, if the annealing temperature is lowered to below 500°C, the acceptor concentration increases before it decreases. This sort of data is compatible with the picture that the heat treatment produces vacancies which act as acceptors and, in addition, interstitials which act as donors. Furthermore, it suggests that the interstitials have a higher diffusion rate than the vacancies and that, at the density of defects present in the germanium, there is little direct recombination of vacancies with interstitials. Most likely, the defects are diffusing to dislocations and the surface of the crystal.

D8. Electrical Properties of the Interface between a Germanium Single Crystal and an Electrolyte. W. H. BRATTAIN AND C. G. B. GARRETT, *Bell Telephone Laboratories.*—It is found that the anodic current from a germanium surface in solutions of KCl, KOH, and HCl is controlled by the supply of holes. The half cell potential consists of three parts: the reversible electrode potential of germanium in the solution; an overvoltage of the usual form, $bkT/e\ln(1-I/I_0)$, where I is the total current flowing (negative in this case); and a term $(kT/e)\ln p_1/p$, where p and p_1 are the equilibrium and actual hole densities near the surface. For *p*-type germanium $p_1=p$, and this term drops out. For *n*-type germanium, anodic current tends to reduce p_1, making the latter term large. Additional holes may be added by light. In this case p_1/p is given by $1+(I+\alpha L)/\alpha I_s$ where L is the added hole current and I_s the hole saturation current in the dark. "α" is the order of 2. If one adds just enough light to keep p_1 equal to p, one gets the same overvoltage curve as for p type. For *n*-type germanium it follows that $(dV/dL)_I=(kT/eI_s)(p/p_1)$ which is identical with the photoresponse of a $p-n$ junction.

D9. Infrared Properties of *P*-Type Germanium. E. BURSTEIN, B. W. HENVIS, AND N. SCLAR, *Naval Research Laboratory.*—Infrared absorption and photoconductivity measurements have been carried out over a range of temperatures on germanium doped with zinc and with indium. At low temperatures where the holes are bound to the acceptor impurities, zinc doped germanium and indium doped germanium exhibit optical absorption involving the photoionization of bound charge carriers. At sufficiently low temperatures, e.g., liquid helium temperature, this absorption is accompanied by photoconductivity which extends to 38 microns, the limit of measurement. The structure in the low temperature absorption curves may be interpreted in terms of optical transitions of holes from bound acceptor levels to levels within the several branches of the degenerate valence band.[1] Differences between the absorption curves of zinc doped germanium and indium doped germanium are attributed to differences in the bound acceptor levels. In indium doped germanium the similarity of the 3.6 microns band at liquid nitrogen temperature (where the holes are free) to that at liquid helium temperature (where the holes are bound) is apparently due to the similarity in character of holes at the top of the valence band to those bound at the impurity centers.

[1] H. B. Briggs and R. C. Fletcher, Phys. Rev. **91**, 1342 (1953).

THURSDAY MORNING AT 10:00

Schermerhorn 501

(P. KUSCH presiding)

Invited Papers on Molecular-Beam Experiments

DA1. Rotational Reorientation Spectra of Molecular Hydrogen and Deuterium. N. F. RAMSEY, *Harvard University.* (30 min.)

DA2. Precision Measurements with Molecular Beams. J. R. ZACHARIAS, *M.I.T.* (30 min.)

Invited Papers on the Neutrino

DA3. Status of an Experiment to Detect the Free Neutrino. Thirty minutes to be divided between C. L. COWAN, JR., AND F. REINES, *Los Alamos Scientific Laboratory.*

DA4. The Electron-Neutrino Angular-Correlation Coefficient in the Decay of Helium 6. B. M. RUSTAD, *Columbia University.* (30 min.)

THURSDAY MORNING AT 10:00

Pupin 329

(I. FANKUCHEN presiding)

X-Rays and Spectra

Invited Paper

E1. Small-Angle Scattering. G. H. VINEYARD, *University of Missouri.* (30 min.)

Contributed Papers

E2. Diffraction of X-Rays by Lattice Imperfections. YIN-YUAN LI AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—We consider the scattered intensity around a reciprocal lattice point of a crystal containing a topological imperfection such that the jth atom is shifted from r_j^0 in the perfect lattice to $r_j = r_j^0 + u(r_j)$. It appears that the phase of the diffracted wave is changed by $2\pi H \cdot u(r)$, where H is the position vector of the reciprocal lattice point concerned, and that the strain affects the diffuse pattern through the Jacobian $\partial(r^0)/\partial(r)$. It is pointed out that two different imperfections produce, in the first approximation, the same small-angle scattering if $\nabla \cdot u$ is the same. Diffuse scattering near a Bragg maximum is calculated for an edge dislocation.

E3. Scattering by Lattices of Deformable Atoms. R. J. GLAUBER, *Harvard University.*—Diffuse scattering due to thermal vibration of lattices is usually discussed under the assumption that the atoms undergo displacement rigidly. To investigate effects of atomic distortion, we consider a model in which the continuous function which yields the nuclear displacements, when evaluated at the lattice sites, is taken to define the displacement of the electron cloud at intermediate points as well. The scattering calculations, which include the effects of arbitrarily many lattice-quanta, are performed by field theoretical techniques described previously.[1] As in the latter work, inelasticity of the collisions may be treated by introducing a time dependent generalization of the correlation function for displacements at two points. The results for the present model are broadly similar in form to those for the rigid case. In particular, the Debye factor modulating the intensity of Laue-Bragg scattering remains unchanged. No diffuse scattering, however, surrounds the central (forward) Laue spot. The intensity of diffuse scattering in the immediate neighborhoods of the other spots is the same as in the rigid case, but intensity differences are introduced in the regions between the spots. Effects in these directions may be observable in x-ray diffraction.

[1] R. J. Glauber, Phys. Rev. **87**, 189 (1952).

E4. Spectral Energy Distribution of 2-Mev X-Rays. JOSEPH DRESNER, *Hospital for Joint Diseases.*—The absorption of a highly collimated beam of 2-Mev x-rays in lead has been accurately measured to a transmission of 0.001 under conditions of good geometry. The amount of scattered radiation reaching the detector was estimated to be about 0.001 of the transmitted beam for an attenuation of 1000. It has been shown[1] that the attenuation curve of an x-ray beam in a given absorber is related to the intensity distribution as a function of the absorption coefficient by a pair of Laplace transforms. This information can be readily converted to give the intensity distribution of the incident beam as a function of the energy. The use of this method is limited to x-ray energies below 3 Mev because of the slow variation of the absorption coefficient μ with energy and by the fact that $d\mu/dE$ changes sign near 3 Mev for heavy elements. The difficulties encountered in obtaining useful experimental data for high-energy radiation will be pointed out. Results obtained for a highly filtered beam of 2-Mev x-rays will be presented.

[1] J. R. Greening, Proc. Phys. Soc. (London) **A63**, 1227 (1950).

E5. The Soft X-Ray Absorption of Tellurium.* ROBERT W. WOODRUFF AND M. PARKER GIVENS, *University of Rochester.*—Absorption measurements were made on thin films of tellurium using a two meter spectrograph with an aluminum grating employed at grazing incidence. The effects of the celluloid substrate, onto which pure tellurium was deposited by vacuum evaporation, were eliminated by comparison of various thicknesses of tellurium on celluloid films of identical thickness. The authors recently reported[1] an absorption band found at about 300A. The investigation has now been extended to shorter wavelengths showing another absorption band which is possibly due to transitions from the N_{II-III} level to the conduction band.

* This work was supported by the U. S. Office of Naval Research.
[1] Robert W. Woodruff and M. Parker Givins, J. Opt. Soc. Am. **43**, 817(A) (1953).

E6. *L*-Emission Spectrum of Zr (40).* N. SPIELBERG, C. H. SHAW, AND J. A. SOULES,† *Ohio State University.*—Precise measurements of the complete *L*-emission spectrum of high-purity zirconium metal have been completed in the wavelength region from 5 to 7A. Line shapes and wavelengths were determined on a vacuum two-crystal spectrometer not yet described in the literature which used etched quartz crystals[1] and a proportional counter detector. The physical resolving power was of the order of 15 000. Wavelength calibrations were made with the aid of well-known shorter wavelength lines in higher orders. Previously unreported structure in both diagram and nondiagram lines has been observed. In particular, γ_1, ($L_{II} \rightarrow N_{IV}$) shows considerable fine structure while $\beta_2(L_{III} \rightarrow N_{IV,V})$ shows no detectable fine structure.

* Supported by the U. S. Atomic Energy Commission.
† Du Pont Fellow 1952–1953.
[1] L. G. Parratt, Rev. Sci. Instr. **6**, 113 (1935).

E7. A Liquefied Gas X-Ray Target.* E. A. WHALIN AND R. A. REITZ, *University of Illinois.*—The target gas, hydrogen, deuterium, or helium is contained in a thin-walled brass cylinder in contact with a low-temperature reservoir. For hydrogen and helium targets the reservoir contains the same liquefied gas as the target, while for a deuterium target the reservoir contains hydrogen. Target cylinders of 1.25-inch diameter with 0.0005-inch walls and 2-inch and 4-inch diameter with 0.001-inch walls have been used. These make well-localized x-ray targets with proton and meson backgrounds from the cylinder walls of 5–10 percent. The target and reservoir are surrounded by a liquid nitrogen cooled radiation shield. The nitrogen shield and vacuum jacket have thin windows allowing one to observe the production of protons of energy >20 Mev and mesons of energy >7 Mev. With a reservoir capacity of 3 liters the loss rate of liquid hydrogen is 40 ml per hour and of liquid helium is 250 ml per hour.

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

E8. Radiation Flux in a Planetary Atmosphere. DANIEL I. FIVEL AND GILBERT N. PLASS, *The Johns Hopkins University.*—The radiation flux in a planetary atmosphere can be calculated neglecting scattering if the transmission function is known between any two levels. After integration over both frequency and the variable conditions along the atmospheric path between two levels, the transmission function can be written in a very simple form involving Legendre functions. This is possible either for a single spectral line or for the Elsasser model of a band which allows approximately for the overlapping of the lines. It is assumed in this derivation that the atmosphere is isothermal, that the fractional concentration of the radiating gas does not vary with height, and that the spectral lines have the Lorentz line shape with its known variation with pressure. However, for several of the major gases that contribute to the infrared radiation flux, the variations of the concentration of the gas and of the absorption with temperature over a long path length are important. In this case it is possible to obtain a rapidly convergent series for the transmission function. The series coefficients are moments of a simple integral involving the distribution of the gas with height and the temperature dependence of the line intensity. Some examples will be presented.

E9. Line Shapes in the Infrared. W. S. BENEDICT,* *The Johns Hopkins University,* AND SHIRLEIGH SILVERMAN,† *Applied Physics Laboratory, The Johns Hopkins University.*—Attempts have been made to study the shape of spectral lines in the fundamental vibration-rotation bands of several diatomic and polyatomic molecules by using high resolution ($\sim$0.2 cm^{-1}) over a broad range of optical densities, so that reliable absorption coefficients may be obtained in the wings of lines far removed from the resonant frequency, as well as at the absorption minimum, or "troughs" between neighboring lines. Results have been obtained for the 4.3μ band of CO_2 and the fundamentals of HCl and CO. The Lorentz line shape appears to be valid only for frequencies close to resonance. At $|(\nu-\nu_0)|$ >0.5 cm^{-1} the pressure dependence of the absorption over the range 0–0.2 atmos, obeys the Lorentz law but the frequency dependence does not. For CO_2 and CO the absorption is less than Lorentzian, while for HCl it is greater. In all cases the deviations increase with $|\nu-\nu_0|$. No evidence for an asymmetrical (Lindholm) shape has been found.

* This portion of the work was supported by the U. S. Office of Naval Research.
† This portion of the work was supported by the U. S. Office of Naval Research and the Bureau of Ordnance, Department of the Navy.

E10. Vibration-Rotation Line Intensities of Diatomic Molecules.* R. C. HERMAN, S. SILVERMAN, AND R. F. WALLIS, *Applied Physics Laboratory, The Johns Hopkins University.*—Using wave mechanical methods, matrix elements have been calculated for the *P* and *R* branches of the 0–1, 0–2 and 1–2 transitions of a diatomic molecule taking into account the interaction of rotation and vibration as well as the mechanical and electrical anharmonicity. For the 0–1 and 1–2 transitions the intensities of corresponding absorption lines in the *P* and *R* branches are proportional in first-order approximation to $(1+4\gamma\theta_K)K$ and $[1-4\gamma\theta(K+1)](K+1)$, respectively, where *K* is the rotational quantum number of the initial state, $\gamma=2B_e/\omega_e$, and $\theta=M_0/M_1r_e$. The quantities M_0 and M_1 are the first two coefficients in the electric dipole moment expansion about the equilibrium internuclear distance r_e. These expressions are a generalization of those obtained for the 0–1 transition by Oppenheimer[1] using matrix mechanics for a special model having $\theta=1$. For HCl where $\theta\sim1$ the results are similar to those of Oppenheimer. For CO, however, where $\theta\sim-1/30$ the effect is negligible. For the 0–2 transition the present theory predicts an appreciable effect for both HCl and CO. New measurements have been made on these molecules which confirm the above predictions.

* This work was supported by the Bureau of Ordnance, Department of the Navy.
[1] J. R. Oppenheimer, Proc. Cambridge Phil. Soc. **23**, 327 (1926).

THURSDAY AFTERNOON AT 2:00

Pupin 329

(G. E. KIMBALL presiding)

Chemical Physics

F1. Adsorption of Carbon Dioxide on Nickel Single Crystal Faces Using a Radiotracer Technique. J. A. DILLON, JR.,* AND H. E. FARNSWORTH, *Brown University.*†—The adsorption of CO_2 (5.8 percent $C^{14}O_2$) on the (110) and (100) faces of a nickel single crystal in the pressure range 1×10^{-6} to 6×10^{-2} mm Hg has been studied using an adsorption chamber containing a thin-window Geiger counter. Maximum adsorption of CO_2 at room temperature takes place on an adsorbed residual gas layer of optimum thickness rather than on the cleanest nickel surface obtained by outgassing in a high vacuum. The CO_2-nickel combination has a rate of adsorption of about 1.5×10^{11} molecules per minute for each face. Dissociation of adsorbed CO_2 is a possible explanation for this low rate. The observed equilibrium adsorption values on the (110) and (100) faces were about equal after 54 hours of outgassing at 985°C. After 32 hours of additional heating at 1085°C, with a pressure during heating of approximately 10^{-7} mm Hg, the adsorption on the (110) face at room temperature was twice that on the (110) face. Possible thermal etching of the (110) face makes the reason for this difference uncertain. Equilibrium adsorption on the (110) face corresponds to a surface coverage of 2 percent. The equilibrium adsorption on the (100) face decreases linearly by 80 percent as the temperature is increased from 30°C to 110°C.

* Now at Geophysics Research Directorate, Air Force Cambridge Research Center.
† Assisted in part by U. S. Office of Naval Research.

F2. Mechanism of Adsorption. I. Theory. B. C. BRADSHAW AND R. A. SHUTTLEWORTH, *Signal Corps Engineering Laboratories.*—The heterogeneity of surfaces is discussed with emphasis on a quantitative relationship between the heat of adsorption of a gas and the amount of surface coverage. The total heat evolved is found to be the sum of a determinable fraction of the heat of condensation of the gas and the actual heat of adsorption. The fraction of the heat of condensation is determined by the number of nearest neighbor molecules when the gas is in the solid state and the number when it is adsorbed as a monolayer. The actual heat of adsorption varies in the ratio of small integers and is found to depend on the number of nearest molecules in the underlying crystalline solid. The adsorption data of Claude, Magnus and Kratz, Kimball and Rideal, Jean Perreau, and others are discussed and shown to be consistent with this relationship. Hysteresis loops appearing in the pressure *vs* volume adsorption-desorption curves below saturation pressures are interpreted.

F3. Mechanism of Adsorption. II. Application. R. A. SHUTTLEWORTH AND B. C. BRADSHAW, *Signal Corps Engineering Laboratories.*—The principles outlined in Part I are used to interpret such phenomena as the effects of particle size and long-range forces on solubility, the destruction of catalytic activity with polishing, and the inverse order of adsorption and desorption.

F4. Effect of Structure and Molecular Weight on the Viscosity of Higher Hydrocarbons at High Pressures.* W. WEBB, J. W. SPENCER,† AND R. W. SCHIESSLER, *The Pennsylvania State University.*—Using a rolling-ball viscometer, the viscosity of eight pure hydrocarbon liquids has been determined from 15 to 50 000 psi at 100°F, 140°F, 210°F, and 275°F. A flexible bellows piezometer was used to determine the density between the same limits of temperature and pressure as the viscosity measurements. The compounds divide themselves into essentially two molecular-weight series. One series is composed of branched paraffins with a molecular weight range of 142 to 535. The other series is composed of aromatic hydrocarbon liquids with a molecular weight range of 182 to 350. In the second series the molecular weight is changed by the addition of a saturated normal branch which is a different length for each compound. Molecular-weight increase in homologous series changes the viscosity variation with pressure in a much simpler fashion than does structure variation. The variation of viscosity (η) with pressure is described reasonably well by an equation of the form

$$\eta/d^{n-1}=\eta_0/d_0{}^{n-1}\exp\{K/T[(d^3/d_0)^n-d^n]\},$$

where (d) is the density at pressure (P).

* Part of the work of Research Project 42 of the American Petroleum Institute.
† Now at California Research Corporation, La Habra, California.

F5. A New Method of Approximate Calculation of Atomic Radii. N. EFREMOV, *1061 Intervale Avenue, New York, New York.*—The proposed method of calculation of effective ionic radii* may be applied to calculation of atomic radii. Periodic system of atoms may be divided into three vertical segments: (1) inert gases, (2) quadruple groups of atoms of elements with valence from 1 to 4, and (3) quadruple groups of atoms of elements with valence from 4 to 7. A generalized scheme of this periodic system is a matrix consisting of several series of simple total numbers (K) which were used for calculation of ionic radii. These matrix numbers characterizing atoms (e.g., Si−13, P−12, S−11, Cl−10) are the first coefficients used for calculation of atomic radii. The second coefficients are ($n+4$), where n is the corresponding quantum number, e.g., (1+4), (2+4), etc. The third coefficients are certain constants ($P=0.01462369$A or $P'=0.0109677$A) which may be derived from Rydberg constant. Thus the transition from calculation of ionic radii to that of atomic radii is a very simple one, e.g.:

$$R_i(\mathrm{Si}\cdots)=(K\times n)P=(13\times2)P=26P=0.38\mathrm{A},$$
$$R_a(\mathrm{Si})=/K(n+4)/P=(13\times6)P=78P=1.14\mathrm{A}.$$

* Paper given at the September, 1953, meeting of the American Physical Society in Albuquerque, New Mexico.

F6. Preparation and Properties of III–IV Compounds. G. WOLFF, P. H. KECK, AND J. D. BRODER, *Signal Corps Engineering Laboratories.*—Considerable interest has been shown in III–V compounds of the sphalerite type, i.e., phosphides, arsenides, and antimonides of gallium indium and aluminum. For the purpose of a more detailed investigation of the properties of single-crystal material, a technique was developed for growing single crystals from solution. Solutions of 10 to 20 atomic percent P, As or Sb in Ga, In, or Al were cooled slowly, after being heated to a temperature slightly above the solubility curve of the phase diagram. The cooling was carried on at such a rate that a constant crystallization occurred. After cooling, the crystals were separated from the Ga, In, or Al excess. The liquid Ga was removed mechanically and chemically from the crystals by dilute HCl at room temperature; In was separated by means of a dilute solution of HCl in glycerol heated to about 180°C; Al was dissolved in dilute HCl thus, single crystal plates of GaP, GaAs, GaSb, InP, InAs, InSb, and

AlSb were obtained. Some of the crystals are up to 12 mm long and 1.5 mm thick. In all cases (111), ($1\bar{1}1$), (001) planes appeared. The twinning plane (111), and the cleavage plane (011), and occasionally (111), were observed in the crystals. Differences between (111), and ($1\bar{1}1$) were found for GaAs, InP, InAs, and AlSb. Thermoelectric tests indicate *n*-type conduction more frequently than *p*-type. Some of these compounds also show a strong photoeffect.

F7. On Bubble Dynamics in a Superheated Liquid.* H. K. FORSTER AND N. ZUBER, *University of California.*—An integro-differential equation describing the growth of a vapor bubble in a superheated liquid was derived: $r\ddot{r}+3/2\dot{r}^2-A(r-1)/r+BJ(t)=q(t)$; r is a dimensionless radius; A, B are physical constants; $q(t)$ is a distributed heat source; and

$$J(t)=\int_0^t \frac{R(t')\dot{R}(t')}{R(t)(t-t')^{\frac{1}{2}}}\left\{\exp\left[-\frac{(R-R')^2}{4a(t-t')}\right]-\exp\left[-\frac{(R+R')^2}{4a(t-t')}\right]\right\}dt'.$$

It is shown that at ordinary superheats the hydrodynamic forces represented by the first two terms of the equation are of importance only in an extremely small time interval of order less than 100 microseconds. Therefore the growth of the bubble almost during its entire "life" is described by the remaining terms, i.e., a nonlinear integral equation. Physical considerations are presented by which the integral is greatly simplified. A solution in the neighborhood of $t=0$ and an asymptotic solution, both in closed form, are obtained. The latter takes the simple form $r=C(t)^{\frac{1}{2}}$ (where C is determined by the physical constants of the liquid and vapor) and although obtained asymptotically agrees well with published experiments down to a few milliseconds.

* This work was supported in part by funds of the U. S. Atomic Energy Commission.

F8. Faraday Effect in Gases.* L. R. INGERSOLL AND D. H. LIEBENBERG, *University of Wisconsin.*—By use of a new sensitive photoelectric method,[1] the Faraday effect has been measured for a number of common gases, at ordinary pressures ($\frac{1}{2}$ to 3 atmos) so as to avoid possible aggregation effects. The gas is contained in a large wire-wound brass tube and a path of 20 m is obtained with the White "folded beam" optical system. The Verdet constants for hydrogen, deuterium, helium, neon, oxygen, nitrogen, and several other gases have been measured, with a probable error averaging 1 percent over the wavelength range 3658A to 9877A, with the aid of 35 carefully calibrated interference filters. Where comparison is possible (e.g., at 5780A), agreement with the work of de Mallemann[2] is quite satisfactory. Most of the Verdet dispersion curves resemble that of water, but oxygen and some other gases show significant deviations.

* Supported by the U. S. Office of Naval Research.
[1] L. R. Ingersoll and W. L. James, Rev. Sci. Instr. **24**, 23 (1953).
[2] Mallemann, Suhner, and Grange, Compt. rend. **234**, 2247 (1952), and earlier papers.

F9. Electrolysis of Sintered Thorium Oxide.* D. L. GOLDWATER AND W. E. DANFORTH, *Bartol Research Foundation.*—Previous studies have been made of electrolytic phenomena in homogeneous crystals of thorium oxide. Experience with electron tube cathodes of sintered thorium oxide has yielded qualitative observations of disintegration of the material with passage of current. Observations of electrolytic effects in tube cathodes are, however, complicated by the possibility of disintegration phenomena resulting from ion bombardment. In the present work, specimens of sintered thorium oxide are mounted in vacuum, and the effects of passing current are studied. A fresh specimen, when heated to 1500° C_b will have a high resistivity of the order of 10^4 ohm-cm. Passage of current reduces resistance according to a law $R=k/Q^n$, where n is in the region of 0.8 and k is of the order of 15 000. The law appears to hold at least as far as $Q\approx 10\,000$ coulombs, $R\approx 1$ ohm-cm. The temperature coefficient of resistance changes from a positive value for the initial (semiconductor) state to a negative value for the final, pseudometallic condition. Evidence of release of electrolytically-produced oxygen will be discussed, particularly with respect to the behavior at the contact between specimen and the metal electrode.

* Supported by U. S. Navy, Bureau of Ships.

F10. The Ion-Yield of the Tritium-Oxygen Reaction. LEON M. DORFMAN AND B. A. HEMMER, *Knolls Atomic Power Laboratory.**—The rate of reaction of tritium and oxygen, initiated by the tritium betaradiation, has been investigated at 25°C, in the absence of mercury vapor, by using a sensitive Bourdon gauge as the manometer. The rate is not linear with time but shows a small continual decrease as the reaction proceeds. The initial reaction rate was found to be directly proportional to the tritium pressure and hence proportional to the radiation intensity. It was independent of the oxygen concentration over the range investigated. The reaction rate shows a slight dependence on the isotopic composition of the hydrogen reactant, tending to rise with increase in the mole fraction of protium. The initial reaction rate may be represented by: $R_0=1.19\times 10^{-4}C_{T_2}(1+0.3m_H)$ where C_{T_2} is the tritium concentration in moles/liter or other absolute concentration units, and m_H is the mole fraction of protium in the hydrogen reactant. On the basis of a requirement of 33 ev per ion-pair in the reactant mixture, the initial ion-pair yield for tritium disappearance or water formation is $(M/N)_0=3.2_3$ for the reaction of pure tritium with oxygen. Material balance measurements indicate that little or no peroxide appears in the product. The mechanism is discussed in the light of these observations.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

F11. Mass Spectra of the Deuteroethylenes. VERNON H. DIBELER AND FRED L. MOHLER, *National Bureau of Standards.*—Samples of the deuteroethylenes have become available to the authors in satisfactory purity, and mass spectra have been measured and corrected for isotopic impurities. As in most hydrocarbons, the probability of removing an H atom relative to the probability in C_2H_4 increases progressively with the number of D atoms whereas the probability of removing a D atom is less than that of removing H from C_2H_4 and increases with the number of H atoms. (The symmetrical and asymmetrical $C_2H_2D_2$ molecules have nearly identical spectra in the mass range 24 to 30.) The probability of removing one H atom is equal to the *a priori* probability times 1.10, $(1.10)^2$, and $(1.10)^3$ in molecules containing one, two, and three D atoms. The probability of removing a D atom is 0.90 in C_2D_4 and is nearly equal to the *a priori* probability times $(0.90)^2$, $(0.90)^3$, and $(0.90)^4$ in molecules containing one to three H atoms. The weighting factors for removing two or more hydrogenic atoms are appropriate powers or products of the individual weighting factors. As the factors, 1.10 and 0.90, are nearly reciprocals, all weighting factors can be approximately represented by positive and negative powers of one constant, 1.10.

F12. Molecular Beam Investigation of the Scattering of Molecules from Surfaces.* F. C. HURLBUT, *University of California, Berkeley.*—Polar flux distribution of air and N_2 molecules scattered from surfaces of mild steel, aluminum, and glass were obtained using molecular beam techniques. Several values of incident angle were used. Polar traverses were not

confined to the incident plane. An ionization gauge-beam detection system was devised to accomplish these measurements. Spatial polar plots of the measured flux distributions for the steel and aluminum surfaces were found to approximate the form of cosine distribution. Similar plots for the glass surfaces were found to have small, broad, bulging deviations from the cosine scattering shape. These findings are discussed in relation to the Maxwell surface interaction model. A modification of the present concepts concerning the formulation of low-density gas-flow boundary conditions is discussed.

* Work supported by the U. S. Office of Naval Research and the U. S. Office of Scientific Research.

THURSDAY AFTERNOON AT 2:00

McMillin Theatre

(G. B. COLLINS presiding)

Mesons, I

Invited Paper

G1. Production of Charged Mesons by Gamma Rays on Hydrogen and Deuterium. P. D. LUCKEY, *Cornell University.* (30 min.)

Contributed Papers

G2. Photodisintegration of Helium above the Meson Threshold.* V. O. NICOLAI AND E. L. GOLDWASSER, *University of Illinois.*—An experiment has been done to measure the contribution to the photodisintegration of the helium nucleus from photons with energies above the meson threshold. The γ-ray beam of the 300-Mev betatron traversed a helium-filled cloud chamber. Runs were made at maximum energies of 135 Mev and 300 Mev. The γ radiation was monitored by a calorimetrically calibrated ionization chamber. The longer recoil ranges associated with helium disintegrations were used to help distinguish them from similar-type reactions in carbon and oxygen which were also present in the chamber as alcohol and water. For two-prong disintegrations the ratio of yields $N(300)/N(135)=1.4$ while for one-prong disintegrations, $N(300)/N(135)=1.2$. To get these numbers the two irradiations were normalized to the same number of photons per Mev at 27.5 Mev, the peak of the giant resonance. Other experimenters, observing photostars in the heavier elements of nuclear emulsions, find a yield ratio of about 3.0, calculated in a similar manner.[1] For a betatron energy of 135 Mev, preliminary results give 0.028-Mev barns for the integrated γ, n cross-section and 0.015-Mev barns for the integrated γ, p cross-section.

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. Kikuchi, Phys. Rev. **86**, 41 (1952).

G3. π^+/π^- Ratios at Low Energies from Complex Nuclei. RYOKICHI SAGANE AND WALTER F. DUDZIAK, *University of California, Berkeley.*—Measurements have been made of charged pion production ratios resulting from the interaction of 340-Mev protons with complex nuclei. For the experiment a 22-in. Spiral Orbit Spectrometer was used.[1] Eight hollow conical targets consisting of the following elements: Be, C, Al, Cu, Ag, Ta, Pb, and U, were bombarded by a monitored proton beam. The charged pions created at 90° to the proton beam were focused by the spiral-orbit principle and detected by Ilford C-2 emulsions. As the pion energy is lowered the effect of the nuclear Coulomb barrier on this production ratio becomes appreciable. At low energies there is a reversal of this ratio (i.e., $\pi^+/\pi^-<1$) with increasing mass number. To illustrate this, the production ratios of C and U are compared at the three measured energies.

Element	π^+/π^- Ratios $T_\pi=12.5$ Mev	$T_\pi=27$ Mev	$T_\pi=37$ Mev
Carbon	5.4	6.0	9.0
Uranium	0.2	0.9	1.2

The obtained results are in general agreement with the previous measurement.[2]

[1] R. Sagane and W. F. Dudziak, Phys. Rev. **92**, 212 (1953); W. F. Dudziak and R. Sagane, U.C.R.L. Report 2304; R. Sagane W. Dudziak, U.C.R.L. Report 2317.
[2] R. Sagane, Phys. Rev. **90**, 1003 (1953); R. Sagane, U.C.R.L. Report 2161.

G4. Photoproduction of π^+ Mesons Near Threshold.* E. L. GOLDWASSER AND G. BERNARDINI, *University of Illinois.*—The photoproduction of π^+ mesons near threshold has been investigated using the University of Illinois 300-Mev betatron, a liquid hydrogen target, and Ilford G-5 nuclear emulsions. The experiment was designed to give information on the angular distribution between 30° and 150° in the laboratory system, and on the excitation function from threshold to 230 Mev. Up to this time, analysis of data from angles $\geq 45°$ gives $d\sigma/d\Omega^*=0.7\times10^{-29}$ cm² per steradian at a photon energy of 180 Mev and at all angles. The statistical error is less than 10 percent. The observed variation of the cross section is compatable with a direct dependence on the meson momentum, p, and is certainly less steep than p^3. If the photon interaction with the nucleon system is subject to a multipole analysis,[1] the above combination of angle and energy dependence is found to arise uniquely from an electric dipole absorption. This type of absorption may be considered from the point of view of several different nucleon models. These will be discussed.

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. T. Feld, Phys. Rev. **89**, 330 (1953).

G5. Photomeson Production from Hydrogen.† T. L. JENKINS, D. LUCKEY, AND R. R. WILSON, *Cornell University.*—Photoproduction of charged mesons from hydrogen has been studied using a magnetic deflection method at gamma-ray energies of 200, 235, and 265 Mev and between 39° and 180° cm. The differential cross sections were least squares fitted to $A+B\cos\theta+C\sin^2\theta$, which assumes only S and P waves, with

the following results:

E(Mev)	A(μb/sterad)	B(μb/sterad)	C(μb/sterad)
200 ± 10	8.5 ± 2.2	-1.9 ± 1.3	1.8 ± 2.9
235 ± 15	10.0 ± 1.0	-2.8 ± 0.8	4.5 ± 1.6
265 ± 20	8.7 ± 1.1	-6.9 ± 0.9	10.4 ± 2.0
(270 ± 40)*	(1.0 ± 1.2)	(-1.0 ± 0.9)	(10.0 ± 1.5)

The last row shows our fit of the same expression to the published M.I.T. and Cornell neutral meson data. Assuming that all the P-wave interaction goes through a resonance state of angular momentum $\frac{3}{2}$ and isotopic spin $\frac{3}{2}$, one would expect the C term for charged mesons to be $\frac{1}{2}$ that for neutrals. Our data indicate a ratio more nearly 1 contradicting this assumption. Had we assumed a $2+3\sin^2\theta$ distribution, C would be about 6 and the agreement worse.

† Supported by the U. S. Office of Naval Research.

G6. $\pi^{\pm}$ Production Cross Sections from Deuterium. WALTER F. DUDZIAK, *University of California, Berkeley.*—An experiment of interest is the measurement of the pion production cross section from the following reaction $p+n\rightarrow\pi^-$. For the experiment hollow conical $(CD_2)_n$ and C targets were mounted on the axis of a 22-in. spiral orbit spectrometer. Charged pions created at 90° to a 340-Mev proton beam were detected by C−2 nuclear emulsions. Preliminary data based on 414 π^- star forming mesons from the $(CD_2)_n$ target yield the following ratios for the negative pion production cross section from deuterium to the negative pion cross section from carbon.

T_π(Mev)	12.5	21	27	37	56
$\frac{\sigma_d^-}{\sigma_c^-}$	0.4	0.4	0.06	−0.09	−0.05

A similar preliminary ratio for positive pions is likewise obtained.

T_π(Mev)	12.5	21	27	37	56	65	66.3	67.5	68.8	70
$\frac{\sigma_d^+}{\sigma_c^+}$	0.5	0.3	0.3	0.3	0.08	0.09	0.05	0.05	0.2	−0.05

From an accurate measure of (1) the π^+/π^- ratio from carbon and (2) the positive pion production cross section from carbon one can determine the production cross sections for deuterium. A preliminary estimate of the integrated π^+/π^- ratio from deuterium at 90° is 12:1. Likewise the preliminary value for the reaction $p+d\rightarrow\pi^++t$ which occurs at $T_\pi=69$ Mev is 5×10^{-31} cm²/Mev Sterad.

G7. Elastic Photoproduction of Neutral Mesons from Deuterium.* B. WOLFE, J. W. DEWIRE, AND A. SILVERMAN, *Cornell University.*—We have investigated the angular distribution for the reaction $\gamma+D\rightarrow\pi^0+D$. The reaction is observed by detecting a coincidence between the recoil deuteron and one of the π^0 decay γ rays. Details of the technique have been reported previously.[1] The differential cross sections are measured for an average γ-ray energy of 275 Mev with a spread of energies from approximately 260 Mev–290 Mev. The results are as follows:

θ_{π^0}(Lab)	76°	94°	110°	130°
$\left(\frac{d\sigma}{d\Omega}\right)\times10^{30}$ (cm²/ster)	6.3 ± 1.0	3.3 ± 0.5	2.7 ± 0.4	1.2 ± 0.3

The data are obtained by taking a CD_2-CH_2 difference for the various angles. To obtain the absolute cross section, independent of the γ-ray detection efficiency, a CD_2-CH_2 difference was measured at 110° for the π^0 by detecting only the recoil deuteron (deuteron angle = 28°). The errors shown apply to the relative values of the differential cross section. The absolute cross section has an additional uncertainty of 20 percent.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] DeWire, Silverman, and Wolfe, Phys. Rev. **92**, 520 (1953).

G8. Elastic Photoproduction of π^0 in Helium.* G. DE-SAUSSURE AND L. S. OSBORNE, *M.I.T.*—The gamma-ray beam of the synchrotron operating at 350 Mev was passed through a chamber containing helium. The recoil alphas arising from the photoproduction of π^0 were detected in photographic plates placed inside the tank. The Ilford GO 400μ plates were developed so as to enable one to discriminate singly from doubly charged particles. That part of the He^3 background from the photodisintegration which falls in the same energy angle region as the recoil nuclei from π^0 production is the result of incoming gamma rays of energies smaller than 150 Mev. It can be subtracted by making a separate run at low energy. From the angle and range measurements, the center-of-mass energy of the incident photon and the angle θ and momentum of the meson were determined on 280 individual events. The following table shows the preliminary results:

θ (center of mass)	20–60°	60–80°	80–100°	100–120°	120–160°	
$\frac{d\sigma(\alpha)}{d\Omega}$	18.5 ± 6	28 ± 7	34 ± 7	16.5 ± 6	1 ± 1	10^{-30} cm²/steradian equivalent photons
$\frac{d\sigma(\alpha)}{d\Omega}\Big/\frac{d\sigma(p)'}{d\Omega}$	2.3	1.6	1.7	0.9	0.1	

* This work was supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Goldschmidt-Clermont, Osborne, and Scott, Phys. Rev. **89**, 329 (1953), and B. T. Feld, Phys. Rev. **89**, 330 (1953). The cross section is assumed to be proportional to $2\cos^2\theta+5\sin^2\theta$ and the part proportional to $2\cos^2\theta$ corresponds to spin flip and has been subtracted.

G9. Elastic Production of π^0 Photomesons from Deuterium.* H. L. DAVIS AND D. R. CORSON, *Cornell University.*—The 310-Mev bremsstrahlung of the Cornell synchrotron was used to study the process $\gamma+D\rightarrow\pi^0+D$. The recoil deuterons were bent through 40° by a uniform magnetic field and were detected by Ilford C-2 200μ emulsions inclined with a vertical angle of 45° to the deuteron trajectory. The particle momentum was determined by observing the horizontal angle of incidence in the plate. Deuterons and protons with the same momentum were separated by observing the difference in grain densities of their tracks. In the momentum interval used protons had energy $\geqslant$50 Mev and were barely detectable; deuterons in the same interval were detectable with ~100 percent efficiency. With the system evacuated plates exposed with no target in position showed no background tracks. An independent check was made of the momentum resolution and the identity of the particles by observing the ranges of particles stopping in plates inclined at 5° to the horizontal. This additional information allows a determination of the particle mass. The resolution of the resulting mass spectrum agreed with the expected momentum resolution. A heavy paraffin-carbon difference was measured at 270 Mev and a π lab angle of 130°. Preliminary results give $d\sigma/d\Omega=3.1\pm1.0\times10^{-30}$ cm² sterad^{-1}.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

G10. Negative μ-Meson Capture in Carbon.* T. N. K. GODFREY,† *Princeton University.*—The experiment reported previously[1] has been completed. Cosmic-ray μ mesons that stop in an organic liquid scintillation counter are selected by an arrangement of coincidence and anticoincidence Geiger counters. In the scintillation counter the mesons may either decay or be captured by nuclei of the carbon in the scintillation liquid. The capture reaction produces either B^{12} or nuclear fragments. The number of electrons emitted by decaying μ mesons and the number emitted by decaying B^{12} nuclei are each counted. From the ratio of these two numbers and the known mean life of the free μ meson a value for the rate of the

μ-meson capture reaction that produces B^{12} is calculated. A comparison between this value and that predicted by applying the theory of orbital electron capture to the capture of μ mesons will be presented.

* Supported by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
† National Science Foundation Predoctoral Fellow.
[1] T. N. K. Godfrey, Phys. Rev. **92**, 512 (1953).

G11. Spectrum of Electrons from μ-Meson Decay.* R. W. WILLIAMS† AND J. H. VILAIN,‡ *M.I.T.*—We have measured the energy spectrum of positons from the decay of muons at rest. Positive pions from a paraffin target in the gamma-ray beam of the M.I.T. synchrotron passed through a cloud chamber in a magnetic field (9000 gauss) and stopped in the wall of the chamber. The electron from the subsequent muon decay was visible in the chamber if it started in a favorable direction; we have obtained 830 such events. In order to obtain an unbiased sample we have restricted the study to electrons of more than 20-Mev initial energy, and have applied to these a strict set of selection criteria. The final sample contained 280 tracks. Comparing this with the calculated spectrum,[1] and using $(207.0\pm0.6)m_e$ for the muon mass, we find, for Michel's parameter, $\rho=0.50\pm0.12$; that is, the spectrum very clearly does not go to zero at the end point.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Presently on leave at Princeton University.
‡ Present address: Ecole Nationale Superieure des Telecommunications, Paris.
[1] L. Michel, Phys. Rev. **86**, 814 (1952).

THURSDAY AFTERNOON AT 2:00

Horace Mann

(JAMES RAINWATER presiding)

High-Energy Electrons; Positrons; Fission

H1. Angular Distribution of Photoelectrons.* W. H. MCMASTER AND F. L. HEREFORD, *University of Virginia*.—The angular distribution of high-energy (0.4–0.7 Mev) photoelectrons produced in Pb and Au foils by linearly polarized photons has been investigated using scintillation counting and pulse-height analysis techniques. A Compton scattered photon beam from Co^{60} provided a source of partially polarized radiation. The cross section for the distribution of K-shell photoelectrons was first calculated by Sauter[1] using Dirac's relativistic wave equation. The cross section is of the form $d\sigma_k=A+B\cos^2\Phi$. In the nonrelativistic limit the second term predominates in agreement with nonrelativistic calculations. For high energies ($>\sim0.5$ Mev), the first term, containing the square of the energy, predominates;[2] resulting in photoemission predominately orthogonal to the electric vector of the incident photon. Experimental results confirm this phenomenon and are in good agreement with the distribution predicted by Suter.

* Supported by U. S. Office of Ordnance Research.
[1] F. Sauter, Ann. Physik **11**, 454 (1931).
[2] F. L. Hereford and J. P. Keuper, Phys. Rev. **90**, 1043 (1953).

H2. Energy Distribution of Secondary Electrons Produced by 1.3-Mev Primary Electrons.* R. A. SHATAS, J. F. MARSHALL, AND M. A. POMERANTZ, *Bartol Research Foundation*.—Utilizing the linear accelerator as a source of 1.3-Mev electrons, the secondary electron emission from thin targets which do not stop the primaries has been investigated. In the usual thick-target experiments, scattered primaries and high-energy secondaries are indistinguishable, whereas the former do not register in the present arrangement. Under these conditions, it has been possible to determine that energetic secondaries (delta rays) constitute about half of the total yield. With a 0.002-in. Ni target the total yield from both faces (I_{sec}/I_{prim}) is 3.6 percent, and the delta-ray yield exceeds 1.5 percent. The latter is at least qualitatively in accord with theoretical expectation. The customary procedure of designating as "true secondaries" all electrons which fail to reach a collector when some arbitrarily-assigned retarding field is applied thus introduces appreciable errors; similarly it is erroneous to regard all energetic electrons leaving a bombarded target as scattered primaries. Preliminary measurements have also indicated that the energy distribution in the low-energy region is roughly similar to that observed when the bombarding energy is low, with the maximum for Ni occurring below 6 ev.

* Assisted by the U. S. Office of Naval Research and by the U. S. Office of Ordnance Research.

H3. Elastic Scattering of Electrons from Nuclei.* ROBERT T. BAYARD AND J. L. YNTEMA, *University of Pittsburgh*.—Considerable discrepancies in the scattering of electrons at large angles by heavy nuclei have been reported between 0.15 and 0.4 Mev and at 2.2 Mev.[1] We have measured the relative scattering of 1-Mev electrons by aluminum and gold at 30°, 60°, 90°, 120°, and 150°. The source of electrons was a Van de Graaff generator and the detectors were anthracene crystals viewed by photomultipliers. The scattering in aluminum is consistent with the α^4 approximation of Matt's theory, as given by McKinley and Feshbach,[2] within the experimental error of 0.4 percent. The scattering in gold was compared with cross sections obtained from those calculated for Hg by Bartlett and Watson[3] using the α^4 approximation to correct for the difference between Hg and Au. The experimental data do not differ by more than 1.5 percent from these theoretical values. Therefore there is no evidence of deviation from Mott theory at 1 Mev.

* Supported in part by joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] E. Kinzinger, Z. Naturforsch. **8a**, 312 (1953), E. Kinzinger and W. Bothe, Z. Naturforsch. **7a**, 390 (1952), W. Paul and H. Reich, Z. Physik **131**, 326 (1952).
[2] William A. McKinley, Jr., and Herman Feshbach, Phys. Rev. **74**, 1759 (1948).
[3] J. H. Bartlett and R. E. Watson, Proc. Am. Acad. Arts Sci. **74**, 53 (1940).

H4. Elastic Scattering of High-Energy Electrons by Nuclei. ALFRED E. GLASSGOLD, *M.I.T.*—The difference in the scattering phase shifts between a finite and a point nucleus has been calculated for two static charge distributions: The nuclear charge is distributed uniformly (1) throughout a sphere of radius R_1 or (2) on a sphere of radius R_2. This phase shift depends on the energy and nuclear radius only through the product kR of the wave number and the nuclear radius. The values of the atomic number used were $Z=13$, 29, 50 and 79, and the values of kR ranged from $\frac{1}{2}$ to ∞. For $Z=79$ and $R=r_0A^{\frac{1}{3}}$ with $r_0=1.1\times10^{-13}$ cm, $kR=3$ corresponds to an energy of about 100 Mev. An interpolation formula has been

developed which gives the change in phase shift for small changes in Z. Comparison will be made with recent experiments.

H5. Čerenkov Radiation from Extended Electron Beams.* M. DANOS, *Columbia University Radiation Laboratory.*—The energy emitted by a flat electron beam having the charge density $\rho=\rho_0[1+\alpha\cos[(\omega/v)(z-vt)]]$ and moving with the velocity $v=c\beta$ at a distance d over the surface of a dielectric with dielectricity constant ϵ is given by

$$P=189I^2\alpha^2\exp\left[-\frac{4\pi d}{\lambda}(1-\beta^2)^{\frac{1}{2}}\right]\frac{\epsilon}{\beta}\frac{(1-\beta^2)(\epsilon\beta^2-1)^{\frac{1}{2}}}{(\epsilon\beta^2-1)+\epsilon^2(1-\beta^2)}\times\mu \text{ watts/cm}^2$$

if the beam current I is measured in ma; $\lambda=\omega/2\pi c$ is the free space wavelength. The dependence of the radiated energy on v is here qualitatively different than in the well known case of cylindrical geometry,[1] where the radiation reaches a maximum at $v\rightarrow c$. If in the plane case a second dielectric is added so as to sandwich the electron beam between the two dielectrica the behavior is similar to the cylindrical case.

An experiment has been performed to detect the Cerenkov radiation at microwave frequencies. The power observed is in reasonable agreement with the theoretical predictions.

* Work supported jointly by the U. S. Signal Corps, the U. S. Office of Naval Research, and the U. S. Air Research and Development Command.
[1] V. L. Ginsburg and I. M. Frank, Doklady Akad. Nauk **56**, 699 (1947).

H6. Scattering of 2.7-Mev Positrons by Au and Al Foils. L. GRODZINS, *Purdue University* (introduced by W. Y. Chang).—Positrons from radioactive sources are selected by a beta-ray spectrograph and sent into a 12-in. cloud chamber illuminated over a depth of 3 in. Helmholtz type coils produce a field within the chamber uniform to greater than 99.5 percent over 10 inches of its diameter. The tracks are photographed with a 35-mm double-lens camera placed above the chamber. Studies of positron interactions with the cloud-chamber gas and foils placed within the chamber are being carried out. Using a Ga^{66} source about 5000 tracks have been photographed of 2.7 ± 0.3 Mev positrons, which have traversed, in a field of 560 gauss, the helium gas and a 0.0001-in. Au and a 0.001-in. Al foil placed within the chamber. These particles enter the chamber through a $\frac{1}{4}$-in. slit, covered with a 0.001-in. Al foil, and have an azimuthal spread of about 3°. Only those positrons which strike the gold foil at an angle of $90\pm10°$ are measured. A more detailed description of the experimental arrangement, the accuracy of track measurement and the analysis of these tracks will be presented (see abstract LA2 by W. Wallenmeyer).

H7. Lifetime for Annihilation of Positrons in Aluminum and Lead. GEORGE H. MINTON, *National Bureau of Standards.*—A coincidence system of millimicrosecond resolution has been employed to compare the lifetimes for annihilation of positrons stopped in lead and aluminum. Na^{22}, which emits a positron of 575-kev maximum energy and a simultaneous 1.3-Mev gamma ray, was used as a source. The gamma rays were detected by scintillation counters employing terphenyl-toluene scintillators and 5819 photomultipliers operated at over 2000 volts. The pulses from the anodes of the photomultipliers were fed directly into two diode coincidence circuits opersted as a differential unit. The curves obtained for coincidence rate *versus* inserted delay were compared with similar curves obtained with gamma-gamma coincidences from Co^{60}. In order to work with similar pulse-height distribution in obtaining the curves, the output of the coincidence unit was gated by differential pulse-height selectors driven from the last dynodes of the photomultiplier tubes and viewing appropriate parts of the Compton spectra produced in the scintillators by the gamma rays. The observed mean life of positrons in aluminum was $(2.9\pm0.3)\times10^{-10}$ second. The lifetime observed in lead was $(3.5\pm0.3)\times10^{-10}$ second. The difference of these two quantities is estimated to be $(6\pm3)\times10^{-11}$ second. Comparisons with previous related experiments will be made.

H8. Annihilation of Positrons in Condensed Materials.* T. A. POND,† *Princeton University.*—The previously described method[1] for comparing the fractions of positrons that annihilate with two photons in different materials has been extended. The ratio of the two-photon fraction in crystalline germanium of 45 ohm/cm resistivity to copper is 1.0009 ±0.0009. Fused quartz shows (0.6 ± 0.1) percent fewer two-photon annihilations than either crystalline quartz or Duraluminum. If this defect is attributed to triplet positronium annihilations, it corresponds, when combined with the data of Bell and Graham[2] to a lifetime for triplet positronium against three-photon annihilation of $(0.9\pm0.5)\times10^{-7}$ sec in fused quartz. Benzene shows 0.7 ± 0.1 percent fewer two-photon annihilations than magnesium. This difference is partially quenched by the addition of small amounts of the free radical, diphenyl picryl hydrazyl, to the benzene. Assuming thermal triplet positronium of mean life 2×10^{-9} sec[2], the observed variation of quenching with concentration of the free radical leads to an exchange cross section between positronium and the unpaired electron of 4×10^{-17} cm[2].

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Washington University, St. Louis, Missouri.
[1] T. A. Pond, Phys. Rev. **91**, 455 (1953).
[2] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 644 (1953).

H9. Fine Structure of Positronium.* ROY WEINSTEIN, MARTIN DEUTSCH, AND SANBORN BROWN, *M.I.T.*—We have extended the experiments of Deutsch and Brown[1] on the Zeeman splitting of the 1^3S state of positronium, using higher R.F. power, and improved control of the magnetic field. The reduction of the three quantum annihilation at resonance ranged from 5 to 20 percent and agreed with the theoretically expected quenching within the experimental uncertainty. The width of the resonance at half maximum, $\Delta H/H\simeq4\times10^{-3}$, agrees with the annihilation width broadened by a doppler effect due to a kinetic energy of the order of 1 ev. The position of the resonance was found to be independent of the nature and pressure of gas in the cavity. He, A, Kr, and CF_2Cl_2 were used at pressures between 1/3 and 4/3 atmospheres. The singlet-triplet splitting of the ground state, calculated to order α^5 from the Zeeman splitting is $\Delta W=2.03350\pm50$ mc, compared with a theoretical value[2] of 2.03370 mc.

* This work was assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission, and in part by the U. S. Signal Corps and the U. S. Air Materiel Command.
[1] M. Deutsch and S. Brown, Phys. Rev. **85**, 1047 (1952).
[2] R. Karplus and A. Klein, Phys. Rev. **86**, 257 (1952).

H10. Angular Distributions of Fission Fragments from 22-Mev Proton Induced Thorium Fission. B. L. COHEN, W. H. JONES, G. H. MCCORMICK, AND B. L. FERRELL, *Oak Ridge National Laboratory.*—The angular distributions of barium, strontium, zirconium, ruthenium, and silver fission fragments from 22-Mev proton induced thorium fission were measured using the internal, circulating beam of the Oak Ridge National Laboratory 86-inch cyclotron. The target consisted of a thin strip of $\frac{1}{2}$ mg/cm[2] thickness of thorium oxide plated on a 0.001-in. platinum foil. The fission fragments were collected in aluminum foils which, after bombardment, were processed chemically to isolate the various fission products; these were then counted to determine the angular distribution. Approximately 60 bombardments were carried out. Within the accuracy of the experiment, all angular distributions are symmetric about 90° and can be well fitted to $I(\theta)=a+b\cos^2\theta$. For Ba, Sr, Zr, Ru, and Ag fission products, b/a is 0.265 ± 0.015, 0.250 ± 0.020, 0.215 ± 0.015, 0.17 ± 0.05, and 0.110 ± 0.015, respectively. (Errors are standard deviations due to statistics only; systematic errors introduce an uncertainty of about

± 0.02). Symmetric fission thus gives a more isotropic angular distribution than asymmetric fission. The data is fitted somewhat better by $I(\theta)=a'+b'\cos^2\theta+d'\cos^4\theta$ where in all cases, d'/a' is about -0.16 and $b'/a'+d'/a'$ is very nearly equal to b/a given above. Possible theoretical reasons for the anisotropic angular distributions will be discussed.

H11. Measurement of the Energy Released per Fission in the Bulk Shielding Reactor. J. L. MEEM, *Oak Ridge National Laboratory.*—The energy released per fission was measured in the Bulk Shielding Reactor using a specially constructed fuel element. The special element had a removable center fuel plate from which disks were punched to facilitate measurement of their activation by exposure in the reactor. A similar uranium-bearing disk was activated by exposure in a known neutron flux. By comparison, the actual fission rate in the special fuel element was determined. The temperature rise across the fuel element was measured at a known rate of water flow, special precautions being taken to prevent heat leakage. The power was thus determined and a comparison with the fission rate gave the heat released per fission in the special element. The net amount of radiation leaking out of the fuel element (less than 0.2 percent) was calculated as a correction to this figure. The energy per fission in the reactor was 193 ± 5 Mev. The energy associated with captures other than these in U^{235} is calculated to be 2.7 Mev. Accordingly, the energy released per fission (exclusive of neutrino energy) is 190 ± 5 Mev.

H12. Measurement of Fission Fragment Ranges in Aluminum.* D. H. TEMPLETON AND E. M. DOUTHETT, *University of California, Berkeley.*—Fission fragment ranges in aluminum can be measured by radio-chemical assay of the fission products in each of a stack of foils adjacent to the fissioning sample. If these foils have thickness of the order of half the range greater precision can be obtained for the *mean range* than if very thin foils are used, because of errors in thickness in the latter case. Measurements have been made by this "thick foil" technique for several products of the fission of U^{238} induced by 18-Mev deuterons or by 335-Mev protons. The forward-backward difference in the deuteron case confirms that a compound nucleus is formed prior to fission. The results in the proton case are explained by the evaporation of many neutrons followed by fission in which the neutron-proton ratio is nearly the same in the two fragments.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

H13. Photofission Cross Sections.* JAMES GINDLER AND ROBERT B. DUFFIELD, *University of Illinois.*—The photofission cross sections of several elements have been measured for bremsstrahlung having maximum energies from 125 to 300 Mev. A scintillation counter was used to detect the fission recoils. For 275 Mev bremsstrahlung the following values were obtained (given as the number of fissions per atom for a flux of one erg/10^{-24} cm^2): 0.34 for tantalum, 0.60 for tungsten, 1.2 for gold, 1.7 for thallium, 2.9 for lead, 6.3 for bismuth, 240 for thorium, 570 for uranium. Cross sections have been calculated from these data. For bismuth and the elements of lower Z, the cross sections increase rapidly with energy above 125 Mev, reaching 8.5 mb for bismuth at 285 Mev in agreement with earlier work.[1] The cross sections of uranium and thorium appear also to increase at the higher energies but the measurements have a large probable error, since they are very sensitive to the large and uncertain cross sections below 125 Mev.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bernardini, Reitz, and Segrè, Phys. Rev. **90**, 573 (1953).

THURSDAY AFTERNOON AT 2:00

Schermerhorn 501

(T. A. READ presiding)

Solid-State Physics, I

Invited Paper

I1. Effects of Pressure on Twelve Rare-Earth Metals. P. W. BRIDGMAN, *Harvard University.* (30 min.)

Contributed Papers

I2. Theory of the Crystal Geometry of the Cubic—Tetragonal Phase Changes.* M. S. WECHSLER, D. S. LIEBERMAN, AND T. A. READ, *Columbia University.*—A general theory of the formation of transformation products in a wide range of crystalline solids which undergo diffusionless phase changes will be presented. Crystallographic features of the transformation are predicted from a knowledge only of the lattice parameters of the initial and final structures and no adjustable constants are involved. These features include the orientation of the plane interface between the two phases, the orientation relationship between the crystal axes in the two phases, and the magnitude and direction of macroscopic distortion accompanying the transformation. The experimental observation that the transformation distortion is inhomogeneous is incorporated in this theory. It is postulated that the essential significance of this inhomogeneity is that it permits the interface plane to be one of zero average distortion. With the use of matrix algebra, explicit expressions are obtained for the direction cosines of the normal to the interface plane as a function of the lattice parameters of the two phases. The detailed formulation of the theory for the cubic to tetragonal transformation will be summarized.

* Work supported by the U. S. Atomic Energy Commission.

I3. Experimental Studies of Diffusionless Cubic—Tetragonal Phase Changes.* T. A. READ, M. S. WECHSLER, AND D. S. LIEBERMAN, *Columbia University.*—Experimental observations on specimens that have partly undergone a crystal structure transformation from cubic to tetragonal will be summarized. These include observations of the orientation relationship between the crystal axes in the transformed and untransformed parts of the specimen, the character of the

interface between the two regions, and the macroscopically observable distortion which accompanies the transformation process. Particular attention will be given to the transformations of this type that occur in barium titanate, indium-thallium alloys, and iron base alloys. It will be shown that these observations are in agreement with the predictions of the analysis given in the preceding paper.

* Work supported by the U. S. Atomic Energy Commission.

I4. Cubic to Orthorhombic Diffusionless Phase Change—Experimental and Theoregical Studies of AuCd.*† D. S. LIEBERMAN, M. S. WECHSLER, AND T. A. READ, *Columbia University.*—The basic ideas and mathematical formulation described above were applied successfully to the analysis of the cubic (β_1) to twinned orthorhombic (β') transformation in AuCd single crystals containing 47.5 atomic percent Cd. Because of the lower symmetry of the low temperature phase in this alloy, the calculations were of necessity more involved. In the mode of transformation studied, a single interface moves slowly along the specimen separating it into the β_1 and β' regions. The transformation is completely reversible with a hysteresis width of 15°C and a transformation temperature on cooling of 60°C. The interface is visible because of the dihedral angle caused by the net macroscopic transformation shear and there is no distortion at the interface. The direction of the interface plane, direction and magnitude of shear, direction of the twin plane, and the orientation relationships were determined experimentally. These same crystallographic features of the transformation were calculated theoretically. The calculated and observed values agree within experimental error. The agreement found between theoretical predictions and experimental observations in the three systems studied thus far constitutes powerful evidence in favor of the theory of diffusionless phase transformations proposed.

* Work supported in part by contract with the U. S. Atomic Energy Commission.
† To be published.

I5. Thermodynamics of Ordering Alloys, II. The Ordered and the Disordered Solid Solutions of the Gold-Copper System. R. A. ORIANI, *General Electric Research Laboratory.*—The thermodynamic activities in solid gold-copper alloys have been measured by the galvanic cell technique, exercising extreme care that equilibrium conditions are attained. Good agreement with the results of previous investigators is obtained in the high-temperature region; the results at lower temperatures clearly demonstrate the two-phase coexistence areas of the phase diagram which lie between successive single phases. The activities of the two components, the free energies, entropies, and enthalpies of solution have been obtained within the disordered field and within the superlattices. The entropy of mixing in the disordered field is somewhat larger than for an ideal solution in the low copper region, but at other compositions shows negative deviations from ideality which correspond to short-range order. The curve of the entropy of mixing at an isothermal which intersects the superlattice phase fields shows deep cusps at the stoichiometric compositions of the superlattices. Assymmetries in the curves of entropies and enthalpies of solution are related to the assymmetry in the boundary between the orthorhombic and the disordered phases.

I6. On the Disordering of Solids by Heavy Corpuscular Radiation. W. S. SNYDER AND JACOB NEUFELD, *Oak Ridge National Laboratory.*—A general method is outlined for determining the number of vacant lattice sites or interstitial atoms in a monoatomic solid exposed to neutron radiation. The colliding atoms are assumed to be within the energy range for which the orbital picture can be applied. Following the treatment of Bohr, the scattering regions of excessive and moderate screening, Rutherford distribution, and electronic collisions are considered separately. The number of vacancies or interstitial atoms as a function of the energy of the primary knocked out atom is given by the solution of certain integral equations that are different for various energy regions considered. It is found that if the velocity of a recoil atom resulting from neutron collision is less than $e^2/\hbar$ (region of elastic collisions) approximately half of its energy is used to produce vacancies or interstitials (for solids composed of atoms having atomic number ($Z>3$)). If the velocity of the recoil atom is above $(e^2/\hbar)$ (region of inelastic collisions) then the energy used to produce vacancies and interstitials is approximately constant (for medium and heavy elements).

I7. On the Equivalence of X-Ray Lattice Parameter and Density Changes in Neutron Irradiated LiF. D. BINGER AND W. J. STURM, *Oak Ridge National Laboratory.*—The question of the equivalence of lattice parameter changes derived from x-ray and density measurements for a lattice containing vacancies and interstitials was investigated. X-ray lattice parameter and density measurements of LiF crystals were made before and after neutron irradiation. The neutron attenuation within the crystals was derived from a combination of calculations and "inhour" measurements. Taking the attenuation into account, the x-ray and density measurements were shown to be equivalent within 10 percent. Annealing data indicates a process of order higher than one.

I8. On the Interpretation of Recovery Phenomena in Cold-Worked Metals.* A. S. NOWICK, *Yale University.*—Low-temperature recovery of electrical resistivity of metals after cold working has been attributed to the annealing out of vacant lattice sites and other point defects created by the deformation. Resistivity measurements, however, are not as suitable for distinguishing dislocation effects as are other phenomena. Especially to be noted are the recovery of internal friction and the dynamic Young's modulus in the neighborhood of room temperature within several hours after deformation, as observed by Köster and others for various metals. It can be shown that the latter phenomena are not attributable to point defects but must be related to the gradual immobilization of originally unbound dislocations, by a process which may be regarded as an early stage of polygonization. In different phenomena where recovery is known to be due to point defects rather than dislocations (as in measurements on samples that have been quenched or bombarded by high energy particles) it is found that the temperature independent factor in the Boltzmann expression for the recovery time falls between 10^{-8} and 10^{-10} sec. This criterion implies that the defect involved makes about 10^4 to 10^6 lattice jumps before being rendered ineffective.

* Work supported by the U. S. Army Office of Ordnance Research.

I9. Methods for Determining the Energy for Fracture Propagation in Plates. J. A. KIES AND H. L. SMITH.—Studies at NRL of fracture propagation in metal sheets have established experimentally the validity of the assumption of a critical condition for fracture based on the balance of release rate of strain energy *versus* the absorption rate in fracturing. This assumption has been further put to use in measuring the energy absorption in fracture propagation for glass plates containing central notches and also for plates containing side notches. The two formulas used and the results obtained therefrom are compared. Both formulas contain the dimensions of the test piece and are therefore useful in predicting size effects.

I10. Energy to Create Fracture Surfaces in Glass. H. L. SMITH AND J. A. KIES.—Previous estimates of the single surface energy of glass have indicated values of 150 to 300 ergs/cm². In order to predict the theoretical tensile strength of glass, Griffith used $S=600$ ergs/cm² in his formula for breaking stress where S is the total work per unit area for the pair of

surfaces in fracturing. The Griffith formula has been modified by Kies so as to apply to finite specimens with internal cracks. In this way surface energies for fracture propagation have been determined which are ten to forty times the surface energy generally quoted. The excess energy is thought to be consumed in activating a multiplicity of separate fracture elements and in creating tear lines. Effects of temperature and humidity on the energy absorption have been measured for cracking in glass plates.

I11. Nucleation of Fracture Origins. E. A. McLEAN AND WALLER GEORGE, *U. S. Naval Research Laboratory.*—The nucleation of fracture origins has been studied in terms of their time rate of appearance, $R(t)$, in centrally-notched foils loaded in tension normal to the notch. The fracture was always less than the "critical" length at which extension is accelerated by the release of strain energy in excess of the specific fracture work. For these lengths fracture growth is accomplished by the interconnection of sub-elements which enlarge from the origins. Values of $R(t)$ are shown to contain substantial fluctuations from a mean trend $\bar{R}(t)$, part of which are approximately periodic in time, t, under load. The periodic component of the fluctuations can be removed from the data by suitable experimental precautions, and is related to compressional stress components parallel to the fracture near the free surfaces. An elastic model for this effect is outlined, based on a solution due to Westergaard.[1] Microscopically the average distance between the fracture origins is related to the grain size, suggesting that points of grain intersection act as nucleation sites. Finally, it is shown that the variance in the periodic-free rate, $[R(t) - \bar{R}(t)]^2$ is a monotonically increasing function of t.

[1] H. M. Westergaard, J. Appl. Mech. **6**, A-49 (1939).

THURSDAY AFTERNOON AT 2:00

Pupin 301

(J. A. WHEELER presiding)

Theoretical Physics, II

IA1. A Complete Bacher and Goudsmit Method. C. W. UFFORD AND S. MESHKOV, *University of Pennsylvania.*—Bacher and Goudsmit[1] developed a theoretical method for the calculation of atomic energy states in terms of the experimentally observed energies of ions of higher ionization. Their results applied to configurations of s and p electrons only. Using fractional parentage coefficients together with equation (16) of a previous calculation,[2] we can give a direct method for obtaining Bacher and Goudsmit's results and can extend these results to configurations containing electrons of higher angular momentum than $l=1$. A term in a given configuration of n electrons is expressed as a linear combination of the terms of the configurations of the ions on which it is built. We must find the coefficients of this linear combination. In general, there are $\binom{n}{r}$ ways of choosing r electrons; the coefficient of each configuration is equal to the number of times this configuration occurs. The energy of each configuration is then expressed as a linear combination of the observed energies of its terms. In the general formulation, there is no specification of equivalence or nonequivalence.

[1] R. F. Bacher and S. Goudsmit, Phys. Rev. **46**, 948 (1934).
[2] S. Meshkov, Phys. Rev. **91**, 871 (1953).

IA2. The d^3 and d^4 Configurations of Vanadium. SYDNEY MESHKOV, *University of Pennsylvania.*—The term values of the d^3 configuration of V *III* are calculated in terms of the experimentally observed energies of the d^4 configuration of V *II*. The formalism used was previously developed.[1] The rms deviation of the calculated terms from experiment is reduced from ± 625 cm^{-1} to ± 244 cm^{-1}. An iterative type calculation is then made for the term values of d^4 in terms of both the experimental energies of d^3 and the calculated values of the still unidentified terms of d^3. The rms deviation is reduced from ± 986 cm^{-1} to ± 663 cm^{-1}. A scheme is devised to calculate the values of the matrix elements in terms of the observed energies, when terms of the same kind appear.

[1] S. Meshkov, Phys. Rev. **91**, 871 (1953).

IA3. Spin-Other-Orbit Interaction in the Theory of Complex Spectra. FREDERICK R. INNES, *University of Pennsylvania.*—The development of this interaction, as given by Marvin,[1] is altered in order to obtain an expression in terms of two-particle irreducible tensor operators. This expansion of the interaction leads to combinations of spherical harmonic and angular momentum operators, the properties of which are discussed. The matrix elements are found using the known methods of Racah and others.

[1] H. H. Marvin, Phys. Rev. **71**, 102 (1947).

IA4. Relativistic Contributions to Magnetic Shielding of Nuclei in Atoms. VERNON W. HUGHES AND WERNER B. TEUTSCH,* *University of Pennsylvania.*—The reduction of an externally applied magnetic field at the nucleus caused by the electronic motion has been calculated for one- and two-electron atoms using the Dirac and the Dirac-Breit equation, respectively.[1] The lowest order term is the usual nonrelativistic expression, as previously calculated from Larmor's theorem or, equivalently, from the Schroedinger equation.[2] Additional terms of relative order α^2Z^2 have also been obtained. In a hydrogen-like atom the relativistic contributions depend on the hyperfine structure state and for $m_J=+\frac{1}{2}$, $m_I=+\frac{1}{2}$ are $-3\alpha^2Z^2$ relative to the nonrelativistic term. For two-electron atoms, they are of relative size $-\alpha^2(Z-\frac{5}{16})\times(Z-0.01)$, as calculated with a first-order Hylleraas function for the $^1S_0$ ground state.[3] For both hydrogen and helium these relativistic contributions are smaller than the present experimental errors in the magnetic moment measurements, but for helium they are appreciable compared to the theoretical knowledge of the nonrelativistic term.[3] For heavy atoms they are estimated to be important compared to experimental errors and to knowledge of the nonrelativistic term.[4]

* National Science Foundation predoctoral fellow.
[1] Method similar to W. Perl and V. W. Hughes, Phys. Rev. **91**, 842 (1953).
[2] W. E. Lamb, Phys. Rev. **60**, 817 (1941); N. F. Ramsey, Phys. Rev. **78**, 699 (1950).
[3] E. Hylleraas and S. Skavlem, Phys. Rev. **79**, 117 (1950).
[4] W. C. Dickinson, Phys. Rev. **80**, 563 (1950).

IA5. Interaction Current Contribution to Hyperfine Structure of Tritium. A. M. SESSLER, *Cornell University,* AND H. M. FOLEY, *Columbia University.*—The vector potential produced by the electron in the neighborhood of the nucleus has been

calculated by second-order perturbation theory, using free-particle intermediate states and hole theory. The zero-order Hamiltonian for the calculation of the magnetic hyperfine interaction corresponds to a fixed-point nucleus. Account must be taken of the fact that near the nucleus the electron motion centers on the proton ("adiabatic" motion). An evaluation of the D-state proton orbital hfs yields the same value as was obtained by Low, working from the adiabatic approximation. Our expression for the vector potential corresponds to a "slip," radius R for the adiabatic electron motion $R=1.9[mc^2e^2/(w_0)\hbar c]a_0$, in agreement with the estimate of A. Bohr. The magnitude of the D-state orbital interaction corresponds, on this simple model, to a value of R 15 times smaller than the above,[1] indicating the unique role of the proton orbital interaction. In view of this large value of R, comparison with experiment allows one to place an upper bound on the amount of interaction current which gives a hfs contribution proportional to R.

[1] E. N. Adams, Phys. Rev. **81**, 1 (1951).

IA6. Internal Conversion in the L and M Sub-Shells. E. L. CHURCH* AND J. E. MONAHAN, *Argonne National Laboratory.*—Relative L and M sub-shell internal conversion coefficients have been computed at their respective thresholds in the non-relativistic limit neglecting screening. Although the expressions obtained are strictly valid only for $Z\ll137$ and vanishing electron momentum, the relative conversion in the various sub-shells may be indicative of the situation in cases of more physical interest. The results obtained for the L shell are in essential agreement with the relativistic calculations of Gellman *et al.*,[1] and the empirical classification of Mihelich.[2] Conversion electron spectra of several heavy nuclei are shown, illustrating the essential validity of the above extrapolation for both the L and M shells in the cases identified thus far.

* On leave from Frankford Arsenal, Philadelphia, Pennsylvania.
[1] Gellman, Griffith, and Stanley, Phys. Rev. **85**, 944 (1952).
[2] J. W. Mihelich, Phys. Rev. **87**, 646 (1952).

IA7. Intermediate Coupling in B^{10}. W. T. SHARP AND H. GELLMAN, *Chalk River Laboratories*, AND G. E. TAUBER,* *National Research Council of Canada.*—The intermediate coupling calculations of Tauber and Wu[1] have been extended to the $J=1$ and $J=3$ states of B^{10} with $T=0$. Harmonic-oscillator wave functions and a nucleon-nucleon interaction of the form $(mP+nQ)V(r_{12})$ are assumed, where P denotes the Majorana and Q the Bartlett operator. The eigenvalues of the energy matrix[2] were calculated on the Toronto Ferranti electronic computer for five different values of the spin-orbit coupling parameter ζ for exponential, Yukawa, and Gaussian potentials $V(r_{12})$, each for two ranges. For four of these six potentials ζ can be chosen to fit the ground state spin $J=3$ and the spins and energies of the two lowest $J=1$ states. Comparison with previous results[1] on Li^6, He^6, and C^{14} indicates that a consistent fit is obtained with a Gaussian potential of range 2×10^{-13} cm. For this potential the values of ζ are 0.7 for Li^6, 4.2 for B^{10}, and 5.0 for C^{14}.

* National Research Laboratories postdoctoral fellow.
[1] G. E. Tauber and Ta-You Wu, Phys. Rev. **91**, 443(A) (1953); Phys. Rev. (to be published).
[2] N. Zeldes, Phys. Rev. **90**, 416 (1953).

IA8. The Magnetic Moment of K^{40} in Intermediate Coupling. G. E. TAUBER AND TA-YOU WU, *National Research Council, Canada.*—The spin $J=4$ of the ground state of K^{40} forms a notable exception to Nordheim's rule and might indicate that pure $j-j$ coupling does not hold for this nucleus. On the other hand, the negative magnetic moment of K^{40} seems to favor $j-j$ coupling, as none of the $L-S$ states give rise to a negative magnetic moment, while one of the states in the $j-j$ limit does. However, by applying intermediate coupling to the configuration $d^{-1}f$ it has been found that even a small spin-orbit interaction gives rise to a negative magnetic moment. A central nucleon-nucleon interaction of the form $(mP+nQ)V(r_{12})$, where P denotes the Majorana and Q the Bartlett operator, is assumed and calculations have been carried out for the exponential, Yukawa and Gaussian types of potential $V(r_{12})$ with various "ranges." It has been found that for a suitable choice of the spin-orbit interaction parameter ζ the experimental value $\mu=-1.29\mu_N$ can be obtained, the exact value of depending on the type of potential and range used.

IA9. On the Phenomenological $N-P$ Interaction.*† M. H. KALOS, *Cornell University*, AND J. M. BLATT, *University of Sydney, Australia.*—A program dealing with the $N-P$ system at low energies has been prepared for the University of Illinois electronic computer. Given central and tensor wells of arbitrary shape, the machine computes the strength of the potentials required to fit the binding energy of the deuteron, and calculates the wave functions which correspond to these potentials. In addition, the singlet and triplet scattering problems at zero energy are solved and the scattering lengths and effective ranges computed. We have applied this program to a phenomenological study of the $N-P$ interaction, using a number of combinations of the usual well shapes with varying ranges and depths. In particular, we have considered the following points: the usefulness of the intrinsic range and well depth parameter in comparing potentials of different shapes; the restrictions imposed on the potentials by the requirement of fitting the low energy triplet data; the possibility that a spin-and-charge independent central force can be used to fit both singlet and triplet data; and the effect of the tensor force on the shape dependent parameter of the effective range theory.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Work begun at the University of Illinois.

IA10. On the Theory of Deuteron Stripping.* W. TOBOCMAN, *Cornell University.*—The deuteron-stripping amplitude, resulting from the usual Born approximation treatment, has the form of an integral over the coordinates of the captured particle (neutron for $d-p$ stripping) and the coordinates of the liberated particle (proton for $d-p$ stripping). Since the ranges of integration include the interior of the target nucleus where the wave functions appearing in the integrand are not known, evaluation of this amplitude has up to now depended on additional simplifying assumptions of questionable validity. It has been found possible to transform the expression for the Born approximation stripping amplitude into a form in which the contribution due to integrations over the interior of the target nucleus is obviously small, being zero when the $N-P$ interaction is assumed to have zero range. This transformation leads to an approximate expression for the stripping amplitude which is an integral over the coordinates of only one particle. This integral involves only well defined functions and the effects due to the nuclear interactions of the various particles are represented in terms of boundary conditions. The methods referred to above can be used to derive the well-known result for the deuteron-stripping cross section due to S. T. Butler.

* Supported by joint program U. S. Office of Naval Research and U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 2:00

Hotel Astor, North Ballroom

(F. H. CLAUSER presiding)

Joint Session of the Division of Fluid Dynamics and the Institute of the Aeronautical Sciences

J1. Aerodynamics of Blasts: Diffraction of Blast Around Finite Corners. J. F. LUDLOFF AND M. B. FREIDMAN, *New York University.* (30 min.)

J2. Pseudo-Transonic Similtude and First-Order Wave Structure. W. D. HAYES, *Office of the U. S. Naval Attache, London.* (30 min.)

J3. Recen' Galcit Hypersonic Experimental Investigations. H. T. NAGAMATSU, *California Institute of Technology.* (30 min.)

J4. Effect of Wind-Tunnel Contraction on Free Stream Turbulence. M. S. UBEROI, *University of Michigan.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Pupin 428

(N. P. HEYDENBURG presiding)

Reactions of Transmutation, II; General Nuclear Physics

JA1. Energy Levels in Ca^{41} from the $Ca^{40}(d,p)Ca^{41}$ Reaction.* C. M. BRAAMS,† *M.I.T.*—Thin targets of calcium oxide, prepared by evaporation of natural calcium onto Formvar films, have been bombarded with deuterons from the MIT–ONR electrostatic generator. The protons emitted at 90 degrees to the incident beam have been analyzed with a 180-degree magnetic spectrograph. Incident deuteron energies from 2.5 to 7 Mev were used. The Q values for the ground state and the first excited state are 6.14 and 4.19 Mev, in good agreement with previous work.[1–3] Sixteen groups have been observed in the region of excitation between 2 and 4 Mev, but the assignment of some of these to Ca^{41} needs further verification, for which bombardments of calcium targets enriched in Ca^{44} and Ca^{42} are being made.

* This work has been supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Fellow of the Elsevier Foundation, Amsterdam, The Netherlands.
[1] V. L. Sailor, Phys. Rev. **75**, 1836 (1949).
[2] Kinsey, Bartholomew, and Walker, Phys. Rev. **85**, 1012 (1952).
[3] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A66**, 565 (1953).

JA2. Electrodisintegration of Cu^{63}.* M. B. SCOTT, A. O. HANSON, AND D. W. KERST, *University of Illinois.*—The external electron beam from the 22-Mev betatron was focused upon a set of copper foils placed inside a Faraday cage. The Cu^{62} activity in 2-mil entrance and exit foils was measured as a function of energy. After correcting for the energy loss in traversing the foils and the 10 mil Cu radiator between them, the normalized ratio of photo- to electro-disintegrations,[1] $F=(A_x-A_0)/(A_0NZ^2r_0^2X)$, was found to be 8.9 at 21 Mev and 9.4 at 15 Mev. The value at 21 Mev can be compared with theoretical values of 9.92, 8.64, and 8.17, respectively, for the electric dipole, magnetic dipole, and electric quadrupole interactions assuming an excitation energy of 17 Mev.[2] The shape of the (γ,n) cross section, using the Faraday cage monitor and the calculated total bremsstrahlung radiation, agreed with that of other investigators using R-meter monitors and detectors intercepting only the forward beam. The absolute values of the cross sections are not yet settled.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. S. Blair, Phys. Rev. **75**, 907 (1949).
[2] Thie, Mullin, and Guth, Phys. Rev. **87**, 962 (1952).

JA3. Deuteron Induced Reaction Studies. N. S. WALL,* *M.I.T.*†—Using the M.I.T. cyclotron as a source of 15-Mev deuterons, in conjunction with a NaI scintillation spectrometer, (d,p) reactions on targets possessing magic or near-magic number of neutrons have been studied. The neutron binding energies of some 27 nuclei have been determined from the ground-state Q values. Where experimental techniques permitted the excited states of the various nuclei were also measured. The interpretation of the results, in general as well as for several particular measurements, will be given. The angular distributions of the protons from the (d,p) reaction on Pb^{207}, Bi^{209}, and Y^{89} were also measured. These distributions are compared to those expected on the basis of Butler's analysis of the deuteron stripping process,[1] even though for the first two nuclei the Coulomb field is expected to be important. The Pb^{208} ground-state proton group shows a striking similarity to the distribution expected for a neutron entering the nucleus with one unit of angular momentum, however, no such interpretation is as obvious for the Bi^{210} case. The Y^{90} ground-state proton group shows an angular distribution characteristic of an $l_n=2$ neutron, but the first excited state angular distribution is not characteristic of a single l_n angular distribution.

* Now at Indiana University, Bloomington, Indiana.
† Supported in part by U. S. Office of Naval Research and U. S. Atomic Energy Commission.

JA4. Photodisintegration of Deuterium by 60–280 Mev X-Rays.* BARBARA DWIGHT SCHRIEVER, E. A. WHALIN, AND A. O. HANSON, *University of Illinois.*—Betatron x-rays of 180 and 280 Mev were incident upon a liquid deuterium target. The protons were detected with 600μ G-5 emulsions placed at 30°, 45°, 75°, 120°, and 150°. The energies of the protons were determined by measuring the grain densities. Confusable mesons were distinguished by plural scattering measurements. Preliminary values of the center-of-mass cross sections are given below in microbarns per steradian with statistical errors of about 10 percent.

θ (cm) \ E (Mev)	70	95	115	145	175	205	235
~35°	12	6.7	7.5	6.1	5.7	7.2	6.1
~90°	15	7.2	6.7	5.5	7.1	10.2	4.6
~155°	7.9	5.3	4.3	3.0	2.8	4.2	4.0

The values at 70 Mev are consistent with angular distributions calculated by Marshall and Guth, and by Schiff, superimposed on an equal isotropic component. The measurements at higher energies are in reasonable agreement with measurements of Littauer and Keck,† and subsequent unpublished measurements by Perry, except for the high value in the 75° plate corresponding to about 200-Mev photons. The source of this discrepancy is being investigated.

* This work is supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† R. Littauer and J. Keck, Phys. Rev. **86**, 1051 (1952).

JA5. Photoprotons from 300-Mev Bremsstrahlung.* P. C. MURRAY, R. I. SCACE,† R. O. HAXBY, AND T. R. PALFREY, JR., *Purdue University.*—Photoprotons of 80±4 Mev energy have been observed at 90° to the 300-Mev gamma-ray beam of the Purdue University electron synchrotron in the first of a series of experiments on photoproton emission. Targets of Be, C, Al, Cu, Cd, Sn, and Pb have been used. The relative cross sections per proton from the above materials, in units of $d^2\sigma/dEd\Omega \times 10^{32}$ cm² Mev^{-1} sterad^{-1} effective quanta^{-1} Z^{-1}, to about 5 percent relative accuracy, are, respectively, 9.2, 8.8, 9.4, 9.6, 9.2, 9.5, and 8.6. The apparatus consists of a three-counter telescope in which coincidences $C_{1,2,-3}$ establish the range interval of the particles, and an oscilloscope recording the pulse heights of coincidence-causing pulses from counters 1 and 2 gives high certainty of correct particle identification. Work is continuing at higher proton energies.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at General Electric Company, Syracuse, New York.

JA6. Nuclear Masses as Integral or Rational Multiples of the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.*—The writer[1] has pointed out before that the masses of nuclei in both the ground and excited states appear to be integral or rational multiples of the mass of the negative electron. Recently Bainbridge[2] published a new table of nuclear masses, in which there are 63 masses with $A \leqslant 34$ and with a probable error of $\pm 0.08m$ or less. If the electron mass m is taken as 0.000 548 770 315 amu, corresponding to the nuclear mass of O^{16} being 29 148.100m, twelve of these 63 masses are integral multiples of m to within $\pm 0.05m$. Furthermore, if our attention is limited to those nuclei for which $A \leqslant 19$ and the probable error is $\pm 0.051m$ or less, there are seven masses out of a total of 28 that are integral multiples of m to within $\pm 0.0125m$. The probability of the latter situation occurring by chance is only 4.25×10^{-6}. The masses of n and p appear to be 1838.625m and 1836.09 375m, respectively. Two values computed from Bainbridge's table are (12 785.999±0.047)m and (30 982.999±0.020)m for Li^7 and F^{17}, respectively.

[1] E. E. Witmer, Phys. Rev. **87**, 237 (A), 1952.
[2] E. Segrè, *Experimental Nuclear Physics* (John Wiley and Sons, Inc., New York, 1953), Vol. I, Part V, Table 16.

JA7. Effect of Knock-on Electrons of Ionization Loss. J. W. GARDNER, *Chalk River Laboratories.*—When an ionizing particle traverses a layer of material, not all the energy it loses need remain in the layer because, even at energies where radiation and cascading are negligible, some energy will usually be carried away by knock-on electrons accompanying the primary particle out of the layer. In general, this effect is only partly canceled by the locally produced knock-ons which accompany the primary *into* the layer. An expression has been obtained for the energy spectrum $N(E, x)dE$ of the electrons accompanying the primary at depth x in the layer, and has been applied to the case of a 1-Bev primary muon traversing the burst chamber described by Carmichael and Steljes.[1] It is found that for $E > 1$ Mev the number of electrons accompanying the primary into the chamber is appreciably less (e.g. 50 percent at $E = 10$ Mev) than the number accompanying it out. Hence, the net energy deposited in the chamber is less than that lost by the primary in traversing it. This effect is particularly noticeable in measurements of comparatively rare large energy losses by the primary,[1] corresponding to the "tail" of the Landau-Symon fluctuation curve.

[1] H. Carmichael and J. F. Steljes, Bull. Am. Phys. Soc. **28**, No. 6, 9 (1953).

JA8. The Range of Protons in Be, Al, Cu, Ag, and Au.* H. BICHSEL AND R. F. MOZLEY,† *Princeton University.*—Protons with energies between 10 and 18 Mev were obtained using the previously described analyzing magnet.[1] The energy of the protons from the analyzing magnet was determined by two independent measurements. One method required a measurement of $\int Bds$ along the proton path and of the angle through which the protons were deflected. The other method determined the radius of curvature by measuring the position of 3 collimating slits in the uniform field region. The two methods gave energies which differed by 0.3 percent. Using the average of the above determinations, a preliminary determination of mean ranges gave:[2]

	Energy	Range
Be	17.35 Mev	399.2 mg cm^{-2}
Al	17.85 Mev	466.7 mg cm^{-2}
Cu	17.91 Mev	588.7 mg cm^{-2}
Ag	17.93 Mev	692.0 mg cm^{-2}
Au	17.56 Mev	849.2 mg cm^{-2}

* Supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
† Now at High Energy Physics Laboratory, Stanford University, California.
[1] R. F. Mozley and H. Bichsel, Phys. Rev. **90**, 354 (1953).
[2] H. Bichsel and R. F. Mozley, Phys. Rev. **90**, 354 (1953).

JA9. The Stopping Power of Several Elements for Protons.* D. W. GREEN, J. N. COOPER, AND J. C. HARRIS, *Ohio State University.*—Experiments on stopping power have been carried out using a modification of the general technique of Madsen and Venkateswarlu.[1] Instead of using foils, the material to be studied was evaporated directly on a LiF target and the resultant displacement of the Li and F resonances measured. Protons accelerated by a Van de Graaff generator were used in measuring stopping power for Cu, Se, Ag, Pb, and Bi. Results were obtained for stopping of protons of energies between 440 kev and 1050 kev. For the sake of comparison with theory, data have been plotted as atomic stopping power divided by $Z^{\frac{1}{2}}$.

* Supported in part by the U. S. Atomic Energy Commission through a contract with the Ohio State University Research Foundation.
[1] C. B. Madsen and P. Venkateswarlu, Phys. Rev. **74**, 648 and 1782 (1948).

JA10. Alpha-Particle Ionization in the Noble Gases and the Formation of Metastable Atoms. WILLIAM P. JESSE AND JOHN SADAUSKIS, *Argonne National Laboratory.*—In the course of experiments on the ionization produced by single alpha particles from polonium in helium, it was found that the presence of minute gaseous impurities greatly increased the ionization observed. Systematic studies of the ionization in helium, to which measured quantities of argon have been added, show an increase in ionization up to 40 percent for approximately 0.1 percent of argon. Similar results have been obtained with CO_2, Kr, and Xe as the contaminant. Preliminary experiments with mercury vapor confirm the large effect already reported by others. A similar increase in ionization in argon is given by the addition of C_2H_2. The increase in ionization seems caused by the production of ions when metastable helium atoms suffer collisions with molecules of the impurity. Such relative collision cross sections calculated from the present results are in reasonable agreement with those derived from other methods. These collision cross sections, however, may possibly be influenced by a parallel reaction involving the production of excited molecules at the relatively high pressures used in these experiments.

FRIDAY MORNING AT 9:00

McMillin Theatre

(ENRICO FERMI presiding)

Business Meeting of the American Physical Society

FRIDAY MORNING AT 10:00

Pupin 428

(WALKER BLEAKNEY presiding)

Symposium of the Division of Fluid Dynamics
Shock Waves in Liquids and Solids

K1. Metal Equation of State from Shock-Wave Studies. J. M. WALSH, *Los Alamos Scientific Laboratory.* (30 min.)

K2. Applications of High Explosives and High-Speed Photography to Physical Research Problems. F. J. WILLIG, *Los Alamos Scientific Laboratory.* (30 min.)

K3. The Characteristics of Shock Fronts in Liquids and Gases. D. F. HORNIG, *Brown University.* (40 min.)

K4. The Structure of Detonation in Some Liquid Explosives. T. P. COTTER, *Los Alamos Scientific Laboratory.* (30 min.)

FRIDAY MORNING AT 10:00

McMillin Theatre

(J. STEINBERGER presiding)

Mesons, II

KA1. Elastic Scattering of 80-Mev π Mesons on Aluminum.* AIHUD PEVSNER,† JAMES RAINWATER, ROSS WILLIAMS, AND SEYMOUR J. LINDENBAUM, *Columbia University and Brookhaven National Laboratory.*—The elastic scattering of positive and negative 80-Mev π mesons in aluminum has been measured. Angular distribution will be presented. An optical model calculation has been carried through, using a complex potential, $V+i\sigma$, inside the nucleus, and a Coulomb potential outside the nucleus up to $l=5$. Results of this calculation for sixteen different potentials for both π^- and π^+ mesons will be compared to the experimental data and to some of the (approximate) predictions of the optical model.

* This work was performed under the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now with the Department of Physics, Massachusetts Institute of Technology.

KA2. A Phase Shift Analysis of the Scattering of Negative Pions by Hydrogen.* R. L. MARTIN, *Cornell University.*—A phase shift analysis of the experimental data on the scattering of negative pions by hydrogen in the energy range 115 to 213 Mev will be presented. The analysis was carried out using the graphical method of Ashkin, and assuming the two P-wave phase shifts of isotopic spin $\frac{1}{2}$ to be zero. The analysis shows a resonance level at about 194 Mev in the state of isotopic spin $\frac{3}{2}$ and ordinary spin $\frac{3}{2}$ for the Fermi-type solution. It is not clear from the analysis whether or not there is a resonance level at a somewhat high energy than that investigated for the state of isotopic spin $\frac{3}{2}$ and ordinary spin $\frac{1}{2}$. The two S-wave phase shifts of isotopic spin $\frac{3}{2}$ and $\frac{1}{2}$ are well behaved and are reasonably proportional to the relative momentum with values of about $-10^*\eta$ and $+6^*\eta$, respectively. The Yang type solution has the same S-wave phase shifts and shows resonances in the P-wave phase shifts of isotopic spin $\frac{3}{2}$ and $\frac{1}{2}$ at about 204 Mev and 174 Mev, respectively. The cross section computed from the above phase-shift is somewhat outside the experimental error from the data.

* This research is supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

KA3. Elastic Scattering of Positive and Negative Pions in Lithium.* ROSS WILLIAMS,† AIHUD PEVSNER,‡ AND JAMES RAINWATER, *Columbia University,* AND SEYMOUR J. LINDENBAUM, *Brookhaven National Laboratory.*—Differential scattering of π^+ and π^- mesons at 80 ± 4 Mev and π^- mesons at 125 ± 8 has been observed between 15° and 170°, with angular resolutions from 4° to 12°. Statistics were good within 10 to 15 percent. Two scintillation telescopes feeding three fast-coincidence circuits, with outputs combined in triple coincidence, reduced background counts to about two per hour. At 80 Mev coulomb interference is pronounced in the π^+ and π^- curves at about 22°. Differential curves in lithium drop rapidly to a minimum of about 1 mb at 75° and then rise by a factor of 4 in the backward direction. At 125 Mev the differential cross sections are larger, but the backward rise is not pronounced.

* Supported by the joint program of the U. S. Atomic Energy Commission and U. S. Office of Naval Research.
† Now at Paul Rosenberg Associates, Mount Vernon, New York.
‡ Now at Massachusetts Institute of Technology, Cambridge, Massachusetts.

KA4. Angular Distribution of π^- Proton Charge Exchange Scattering at 40 Mev. I. Apparatus.* A. ROBERTS AND J. TINLOT, *University of Rochester.*—We have measured the yield of π^0 mesons from CH_2 and C targets by detecting coincident photons. π^- mesons entered the targets with 43-Mev energy and emerged with 34 Mev. The weighted mean energy was 40 Mev. Four photon telescopes, consisting of two counters each, were disposed so that their axes defined a regular tetrahedron centered on the target. Coincidences from the six possible pairs of telescopes were recorded, giving a measure of π^0 yield in the approximate forward, backward, and 90° directions. The counting rate from C was about one-half that from hydrogen. Assuming that the π^0 distribution has the form $a+b\cos\theta+c\cos^2\theta$, we have calculated the probability of detecting a π^0 meson in each pair of telescopes as a function of a, b, and c. A simple analog computer was used to evaluate solid angle, and the shower theory of Wilson[1] was used to estimate the photon conversion efficiency. We can then evaluate a, b, and c from the three experimental determinations.

* This work was supported in part by the U. S. Atomic Energy Commission.

[1] R. R. Wilson, Phys. Rev. **86**, 261 (1952).

KA5. Angular Distribution of π^- Proton Charge Exchange Scattering at 40 Mev. II. Analysis of Results.* J. TINLOT AND A. ROBERTS, *University of Rochester.*—Using the results obtained in the experiment described in the previous paper, we find a π^0 distribution: $(0.35\pm0.08)-(0.91\pm0.15)\cos\theta+(0.50\pm0.24)\cos^2\theta$ mb/sterad. The corresponding total cross section is 6.5 ± 1.4 mb. The uncertainties are standard deviations, and include an estimate of error in the computer data and shower theory. Assuming that only the phase shifts α_{11}, α_3, α_{33} contribute to the scattering at this low energy, we deduce the values $\alpha_{33}=7.8°\pm1.2°$, $\alpha_1-\alpha_3=8.3°\pm1.4°$. The additional condition $\alpha_{33}+\alpha_1-\alpha_3=15.8°\pm1.1°$ is obtained. α_3 and α_1 cannot be determined individually from a measurement of charge-exchange scattering alone. The total cross section agrees well with our previous value,[1] and the phase shifts are consistent with those obtained by Barnes *et al.*[2] from 40 Mev $\pi^\pm$ elastic scattering. The latter agreement is evidence for the validity of charge independence in pion-nucleon scattering.

* This work was supported in part by the U. S. Atomic Energy Commission.

[1] A. Roberts and J. Tinlot, Phys. Rev. **90**, 951 (1953).
[2] Barnes, Angell, Perry, Miller, Ring, and Nelson, Phys. Rev. (to be published).

KA6. Charge Exchange Scattering of Negative Pions at 42, 30, and 20 Mev in Hydrogen. W. SPRY, *University of Rochester.*—A measurement of the total cross section for the process $\pi^-+P\rightarrow\pi^0+N$ has been made at each energy using CH_2 and C targets in a difference experiment. The results are computed from the number of single-decay gamma rays detected and a transition curve indicates that these gamma rays have the energy spectrum expected for π^0 decay at these energies. The cross sections are: $6(42\text{ Mev})=6.9\pm0.7$ mb; $6(30\text{ Mev})=5.9\pm0.5$ mb; and $6(20\text{ Mev})=5.2\pm0.4$ mb. The quoted errors are statistical standard deviations only and represent the errors in relative cross sections. The estimated standard deviation in each cross section as an absolute measurement is ±15 percent. The computations assume an isotropic π^0 distribution. Adjustment to the observed 42-Mev distribution[1] has not been made, but will increase the total 42-Mev cross section by less than 10 percent. The estimated error in π^- energy is ±2 Mev.

[1] J. Tinlot and A. Roberts, University of Rochester, abstract KA5, this meeting.

KA7. Elastic Scattering of 160-Mev Pions in Emulsions.* R. A. GRANDEY AND A. F. CLARK, *Carnegie Institute of Technology.*—The elastic scattering of pions from hydrogen has been studied in nuclear plates exposed to the nominal 160-Mev positive and negative external pion beams of the Carnegie synchrocyclotron. Ilford G-5 plates exposed to negative 160-Mev pions were "area scanned." On the basis of 28 elastic scatterings, a cross section for nonexchange scattering of (12.5 ± 3.5) millibarns was found. The mean free path for star formation on the basis of 1000 stars is $\bar{l}=(28.4\pm1.7)$ cm. Plates exposed to the positive pion beam are being scanned alone the track. A total of 32 elastic scatterings have been found. Accidentally, the energy, (151 ± 7) Mev, is exactly one of the energies used by the Columbia plate group (1) in exposures to their internal positive pion beam. Addition of their 41 events gives a total cross section $\sigma=(142\pm25)$ millibarns and a least squares fit to the angular distribution gives $d\sigma/d\Omega=(6.5-4.2\cos\sigma+14.5\cos^2\beta)$ millibarns per steradian. The mean free path for stars on the basis of 241 stars is $\bar{l}=(31.7\pm2.0)$ cm in excellent agreement with the negative pion value corrected for the coulomb effect, (31.9 ± 1.9) cm. Work is in progress to improve the statistics.

* This work is supported by the U. S. Atomic Energy Commission.
[1] Homa, Goldhaber, and Lederman, Phys. Rev. (to be published).

KA8. Spectroscopy of π- and μ-Meson X-Rays.* S. DE BENEDETTI, M. B. STEARNS, M. STEARNS, AND H. J. RICHINGS, *Carnegie Institute of Technology.*—The x-rays from capture of negative π and μ mesons in atomic orbits have been studied analyzing the pulses produced in a NaI scintillator with a 24 channel selector. This operated simultaneously with the signal from a coincidence-anticoincidence telescope which revealed the appropriate mesons stopping in different targets. The energy range from 20 to 250 kv was studied using targets from $Z=4$ (Be) to $Z=20$ (Ca). Well-defined peaks (instrumental widths from 45 percent at low energy to 20 percent at high energy) were observed, corresponding to K lines ($2p$ to $1s$), L lines (presumably $3d$ to $2p$), and M lines (presumably $4f$ to $3d$). The L lines often exhibited a structure indicating the presence of transitions from $n\geq4$ levels to the $n=2$ level. The energies agree with elementary theory within the experimental error of roughly 10 percent. At low Z the intensity is small for both π and μ mesons because of competition with Auger effect; in the case of π mesons it decreases at higher Z because of nuclear capture.

* Work supported by U. S. Atomic Energy Commission contract.

KA9. Yields of π- and μ-Meson X-Rays in Low Z Materials.* M. STEARNS, M. B. STEARNS, S. DE BENEDETTI, AND L. LEIPUNER, *Carnegie Institute of Technology.*—The radiative transitions of π and μ mesons have been observed for elements $Z=4$ to $Z=20$. The radiative yields from both mesons are depressed at low Z because of competition from the Auger effect. The μ-meson yields level off at sufficiently high Z while the π-meson yields go through a maximum and then decrease because of nuclear capture which dominates at higher Z. The percentage of π mesons in the $2p$ state which radiate to $1s$ varies from approximately 30 percent to 0 percent in the range $Z=4$ to $Z=11$ and seems to fall appreciably faster than Z^{-3}. These values are obtained by comparing the π and μ $2p-1s$ radiation yields for the same Z and same geometry and by measuring the number of π's arriving in the $n=2$ level from higher transitions. For the π $3d-2p$ transition nuclear capture becomes important around $Z=13$ and completely dominates by $Z=20$, while the Auger effect enters around $Z=9$ and completely dominates at $Z=6$. For the $2p-1s$ transition we have found no appreciable difference between C and CH radiation yields.

* Work supported by U. S. Atomic Energy Commission contract.

KA10. Density Effect for Ionization Energy Losses in Gases. E. D. PALMATIER, J. T. MEERS, AND C. M. ASKEY, *The University of North Carolina.*—The ionization energy losses of relativistic mu mesons in argon gas have been studied in a proportional counter at various pressures up to 40 atmospheres. The analysis of the behavior of the Landau distributions as a function of gas pressure and meson energy will be presented. Our results indicate that the effect is readily observable at these pressures and is much stronger than has been predicted by previous theoretical work.

FRIDAY MORNING AT 10:00

Pupin 301

(E. L. HAHN presiding)

Contributed Papers on Magnetic Resonance

L1. Self-Quenching Superregenerative Radio-Frequency Spectrometers.* P. J. BRAY, *Rensselaer Polytechnic Institute.*—Empirical evidence suggests that there is little intrinsic difference in sensitivity of signal detection between the externally quenched and self-quenched superregenerative spectrometer. Since this question is of importance in the study of nuclear magnetic moment resonances and pure quadrupole spectra in solids, the factors governing the response of the self-quenched and externally quenched detectors will be reviewed with special application to the response pattern of the self-quenched oscillator. Details of several self-quenched spectrometers will be given for frequencies between roughly 15 and 300 mcps along with sensitivity data in the form of signal-to-noise ratio measurements of quadrupole resonances in standard compounds at various temperatures. Nuclear quadrupole resonance temperature dependence studies employing self-quenching spectrometers will be illustrated with application to some previously reported Cl^{35} resonances.[1] Resonances in a considerable number of previously uninvestigated compounds will be reported.

* Research supported by RPI Research Committee.
[1] P. J. Bray and P. J. Ring, J. Chem. Phys. (to be published).

L2. Nuclear Magnetic Resonance as a Criterion of Chemical Bonding. RICHARD A. OGG, JR., *Stanford University* (introduced by L. I. Schiff).—Study of high-resolution proton magnetic resonance at 30 megacycles in absolutely anhydrous liquid ammonia has shown the expected triplet character, resulting from spin-spin interaction with the N^{14} nucleus. A trace of water impurity, undetectable by ordinary analytical procedures, suffices to alter the proton resonance to a single sharp line. This is correlated with the exchange rate of protons between molecules catalyzed by the acid-base reaction with water molecules. It is apparent that the ordinary so-called "hydrogen bonding" in liquid ammonia has no effect on spin-spin interaction. It is suggested that spin-spin interaction between nuclei results only when true covalent sharing of electrons takes place and that this offers a truly operational criterion of covalent bonding.

L3. Nuclear Magnetic Resonance Spectra of Boranes and Derivatives. JOHN KELLY, JAMES RAY, AND RICHARD A. OGG JR., *Stanford University* (introduced by L. I. Schiff).—High resolution proton magnetic resonance spectra have been studied (both at 30 and 40 megacycles) in liquid samples of $B_3N_3H_6$, B_2H_6, B_4H_{10}, and B_5H_9, as well as in some of the alkyl derivatives of these substances. Additional studies have been made on deuterium oxide solutions of $NaBH_4$. Fluorine magnetic resonance spectra have been studied in BF_3 and a number of addition compounds of this substance. The fine structure of the various spectra results in part from chemical shift and in part from spin-spin interaction. These are distinguished both by magnetic field dependence and by use of substances enriched in the respective boron isotopes. Correlations with the structures of the various substances are discussed. Among the most interesting aspects is the behavior of the so-called "bridge" protons in the boranes. The chemical shift of magnetic resonance of these as compare to terminally bonded protons is toward higher magnetic field. This effect and the spin-spin interaction details are discussed in relation to the theoretical aspects of the proton bridge bond.

(Abstract withdrawn.)

L5. The Ratios of Quadrupole Coupling Constants of Isotopes and Their Variation with Temperature.* T. C. WANG AND C. H. TOWNES, *Columbia University.*—One might expect the ratio of coupling constants for Cl^{35} and Cl^{37} in any molecule to be dependent on nuclear properties only and not on the molecular environment. Measurements on nuclear quadrupole resonances in solids show, however, that this ratio varies with temperature as well as that it is dependent on the molecular environment.[1] A decrease of temperature from 300°K to 78°K decreases the ratio $eqQ_{Cl^{35}}/eqQ_{Cl^{37}}$ by as much as 0.02 percent. Measurement of the quadrupole coupling ratio of Sb^{123} to that of Sb^{121} in several antimony halides and in stibnite shows similar effects. This ratio ranges from 1.274714 to 1.274770 depending on molecular environment. The asymmetry parameter η for the two antimony isotopes agrees to less than 0.01 percent. The change of ratio can be attributed largely to molecular vibrations. Extending Bayer's discussion[2] of thermal vibrations, the variation in coupling ratio can be calculated for the case of p-$C_6H_4Cl_2$ where the vibrational frequencies are known. The calculated change in ratio between 300°K and 78°K is 2.2×10^{-5}, whereas the measured value is $(4.7\pm1)\times10^{-5}$.

* Work supported jointly by the U. S. Signal Corps, U. S. Office of Naval Research, and U. S. Air Force Research and Development Command.
[1] Wang, Townes, Schawlow, and Holden, Phys. Rev. **86**, 809 (1952).
[2] H. Bayer, Z. Physik **130**, 227 (1951).

L6. Spin-Orbit Interaction in RbF and CsF.* G. BEMSKI,† W. A. NIERENBERG, AND H. B. SILSBEE, *University of California, Berkeley.*—The structure of fluorine nuclear magnetic resonance line in RbF and CsF has been investigated as a function of magnetic field between zero and 1000 gauss by the molecular beam technique. This corresponds to the range from complete Zeeman to complete Paschen-Back extremes for internal coupling. RBF results check the statistical theory[1] for the line shape considering only cosine interaction between the F^{19} nucleus and the molecule. The line shape for all field values fit the theoretical curves with just one parameter, the strength of the coupling based on half-width of the line. The coupling constant c/h is measured to be 11.1 ± 0.6 kc/sec in good agreement with 12 ± 3 kc/sec from the electric resonance measurements.[2] The CsF results, particularly at and near zero field, are in violent disagreement with the theory. Possible interpretation is marred by presence of Cs^{133} quadrupole lines but may be due to dimerization.[3]

* Supported in part by the U. S. Office of Naval Research.
† Now at Bell Telephone Laboratories, Murray Hill, New Jersey.
[1] W. A. Nierenberg, Phys. Rev. **82**, 932 (1951).
[2] V. Hughes, Phys. Rev. **79**, 314 (1950).
[3] Ochs, Coté, and Kusch, J. Chem. Phys. **21**, 459 (1953).

Invited Papers

L7. Microwave Resonance in Color Centers. E. E. SCHNEIDER, *University of Durham, England (temporarily at Duke University).* (30 min.)

L8. Polarization of Nuclei in Metals by Magnetic Resonance. A. W. OVERHAUSER, *Cornell University.* (30 min.)

L9. The Solid-State Cyclotron. CHARLES KITTEL, *University of California, Berkeley.* (30 min.)

FRIDAY MORNING AT 10:00

Casa Italiana, 1161 Amsterdam Avenue

(R. P. SHUTT presiding)

General Nuclear Physics

LA1. Initial Performance of the Large Bartol Van de Graaff.* C. P. SWANN, *Bartol Research Foundation.*—The large Van de Graaff has been brought to a first stage of completion. Usable currents have been obtained with energies greater than 5 Mev; the generator has operated continuously, supplying several microamperes of magnetically resolved protons at 4 Mev. Voltage limitations are at the moment imposed by difficulties associated with delivering charge to the belt. The generator is housed in a tank designed for a pressure of 300 psi which is 35 ft high and 12.5 ft in diameter. The porcelain accelerating tube, 20 ft in length, has electrodes of inner diameter 8 inches. Baffles are spaced at intervals of 3.5 ft throughout the length of the tube to suppress secondary electrons. The combined advantages of the Bartol low pressure rf ion source and a high pumping speed eliminate the necessity of a second tube for differential pumping. Some characteristics of the reactions $Li^7(p,n)Be^7$, $Li^7(p,n)^*Be^7$, and $Li^7(p,p')^*Li^7$ will be discussed. The generator has also been employed as a neutron source to excite Ba^{137m} and Hg^{199m} as a function of neutron energy.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

LA2. A Study of Cloud-Chamber Distortions. W. WALLENMEYER, *Purdue University* (introduced by W. Y. Chang).—In order to know the behavior of a newly built cloud chamber with magnetic field which is being used to study position scattering (see another abstract by L. Grodzins), an investigation was made of the various types of distortions, such as those due to (1) the optical system, (2) the turbulences during expansion, (3) the multiple scattering in the gas, and (4) the shrinkage of the film. The magnitudes of the possible errors in the curvature measurements (with and without field) were determined experimentally using internal conversion electrons from C_s^{137}, which traversed the helium gas in the cloud chamber. The experimental results have been analyzed, interpreted, and wherever possible, presented in curves. It shows that an overall probable error of 5 percent or less is to be expected, when the energy of an electron or a positron of about 3 Mev is determined from the measurements of the curvature and the magnetic field.

LA3. Microton Resonators. H. F. KAISER, *Naval Research Laboratory.*—The microtron[1] electron cyclotron depends upon a cavity resonator both for its electron source and for turn acceleration. The particular geometrical requirements such a resonator has to meet in a conventional microtron such as orbit clearance, gap length, aperture, and magnetic gap are discussed for a series of resonator types. The confocal ellipsoidal-hyperboloidal resonators due to Hansen and Richtmyer[2] seem to be best in respect to shunt resistance and associated Q. An analytical procedure for determining the parameters of such resonators for given accelerator conditions is developed. Resonators found to be practical in X and K band microtrons[3] will be illustrated and discussed.

[1] V. J. Veksler, Phys. USSR **9** (3), 153–158 (1945).
[2] W. H. Hansen and R. D. Richtmyer, J. Appl. Phys. **10**, 189–199 (1939).
[3] H. F. Kaiser, Phys. Rev. **87**, (1) 183 (1952); **91**, 456 (1953).

LA4. Longitudinal and Transverse Stability in Linear Accelerator Systems. G. BREIT, *Yale University.**—Relations between the two stabilities may be seen in terms of

$$\frac{d^2\eta}{dx^2}+\left[-\frac{3e}{2mv^2}\frac{\partial \mathcal{E}}{\partial x}-\frac{e}{2mv^3}\frac{\partial \mathcal{E}}{\partial t}+\frac{3e^2\mathcal{E}^2}{4m^2v^4}\right]\eta=0,$$

and of

$$\frac{d^2\rho}{dx^2}+\left[-\frac{e}{2mv^3}\frac{\partial \mathcal{E}}{\partial t}+\frac{3e^2\mathcal{E}^2}{4m^2v^4}\right]\rho=0,$$

$\rho=r(v)^{\frac{1}{2}}$, $\eta=(v)^{\frac{1}{2}}(x-x_0)$, x = longitudinal coordinate, x_0 = equilibrium x, $v=dx/dt$, $\mathcal{E}$ = longitudinal electric field. Relationship of action of a gap to strong focusing and the role of $\int d\mathcal{E}_x/dt=0$ in going across gap will be discussed in a comparison of traveling wave and separate gap accelerators.

* Assisted by joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission and by Office of Ordnance Research, U. S. Army.

LA5. Stability of a Linear Accelerator with Independently Excited Cavities. M. H. HULL, JR., L. C. BIEDENHARN, P. B. DAITCH, AND R. L. GLUCKSTERN, *Yale University.**—Calculations have been performed for various modes of operation of a heavy-particle linear accelerator with independently excited acceleration gaps. The motivation of the calculations is to be found in the theory of such accelerators given by G. Breit and discussed in the preceding abstract. The longitudinal and transverse stability in various portions of the accelerator, as well as the initial phase acceptance range and final energy definition will be discussed both from the standpoint of the linear approximation, conveniently treated by means of matrices, and with the inclusion of nonlinear effects. Special attention will be given the so-called "rocking" mode of operation related to that suggested by Good,[1] where successive sections or groups of sections are operated so as to have alternate focusing and defocusing actions on the transverse or longitudinal oscillations of the beam. It will be shown that satisfactory stability can be obtained in this way without auxiliary equipment, at least in the higher energy portion of the accelerator.

* Assisted by joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission and by Office of Ordnance Research, U. S. Army.
[1] M. L. Good, Phys. Rev. **92**, 538(A) (1953).

LA6. Continuous Parameter Approximation in a Linear Accelerator with Independently Excited Cavities. R. L. GLUCKSTERN, P. B. DAITCH, L. C. BIEDENHARN, AND M. H.

HULL, JR., *Yale University.**—Longitudinal and transverse stability for a linear accelerator with separately excited rf cavities was carried out by considering small deviations of velocity, phase, transverse displacement, and transverse angular divergence from some "equilibrium" particle. In this approximation the longitudinal and transverse oscillations separate, and the action of each cavity may be expressed by means of two-dimensional matrices mentioned in the preceding paper. If the design parameters on which these matrices depend vary slowly from section to section, stability will exist when the eigenvalues of the matrices are less than unity in absolute value. For oscillatory behavior the energy deviation, phase deviation, and transverse deviations of position and direction are damped due to slow variation of parameters after n sections according to

$$\delta E/E \sim E_n^{-5/8} V_n^{1/4} |\sin\varphi_i^{(n)}|^{1/4} l_n^{-1/4},$$
$$\delta\varphi \sim E_n^{-3/8} V_n^{-1/4} |\sin\varphi_i^{(n)}|^{-1/4} l_n^{1/4},$$
$$\delta r \sim E_n^{1/8} V_n^{-1/4} |\sin\varphi_i^{(n)}|^{-1/4} l_n^{1/4},$$
$$\delta r' \sim E_n^{-5/8} V_n^{1/4} |\sin\varphi_i^{(n)}|^{1/4} l_n^{-1/4},$$

where E_n = energy, V_n = gap voltage, $\varphi_i^{(n)}$ = input phase, and l_n = drift length in the nth section.

* Assisted by joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission and by Office of Ordnance Research, U. S. Army.

LA7. Doubly Ionized Helium Ion Source. J. W. BITTNER, R. G. HERB, R. D. MOFFAT, AND J. A. WEINMAN, *University of Wisconsin* (received by wire).—Singly ionized helium ions, from a low voltage arc source, are accelerated to an energy of about 400 kev by means of a small electrostatic generator built inside the high voltage electrode of the Wisconsin 4-Mev electrostatic accelerator. Foot note 1 the ions then pass through a capillary tube $\frac{3}{16}$ in. in diameter and 8 in. long, into the center of which oxygen is introduced at the rate of approximately 10 cc/hr. apuroximately $\frac{1}{4}$ of the ions emerging from this tube and entering the accelerating tube of the 4-Mev accelerator are doubly ionized. The doubly charged particles emerging from the accelerator are seqarated from other components of the beam by means of a magnetic analyzer. The total doubly charged beam at the output of the accelerator is 0.6 micro amps and after passing through an electrostatic analyzer it is .3 micro amp 0.3 microamp. Work supported by the Wisconsin alumni research foundation and the U. S. atomic energy commission.

LA8. Elastic Scattering of Alqha Particles by Carbon. W. HABERLE, J. W. BITTNER, R. D. MOFFAT, *University of Wisconsin* (received by wire).—The elastic scattering of alpha particles by carbon has been observed in the bombarding energy range 4 to 6 Mev. Doubly charged alpha particles (see previous abstract) were passed through the electrostatic analyzer and into a scattering chamber containing propane gas at a pressure of 2 mm Hg. Proportional counters detected the particles scattered at 90 degrees and 171 degrees in the center of mass system. A strong resonance was observed at approximately 4.3 Mev and a broad one at about 5.8 Mev. Angular distributions at these anomalies suggest even parity and $J=4$ and 2 respectively for the associated levels in oxygen. A small, sharper resonance ojcurs at 5.3 Mev. Work at higher energy and other angles is in progress. Work supported by the Wisconsin alumnii research foundation and the U. S. atomic energy commission.

Footnote 1 Herb, Turner, Hudson, and Warren, Lhys. Rev. **58**, 579 (1940).

LA9. On the Use of Wires Embedded in Nuclear Emulsions to Investigate Reactions Induced by High-Energy Neutrons.* E. G. SILVER AND R. W. WANIEK, *Harvard University.*—Previous experiments on interactions induced by high-energy neutrons (90 Mev) in the nuclei of emulsions have suffered from the lack of unambiguous identification of the type of nucleus in which the event occurred.[1,2] To obviate this ambiguity we have resorted to the use of thin filaments embedded in Ilford G-5 electron sensitive emulsions.[3] We have, so far, used Nylon, molybdenum, and tungsten filaments, 10 to 28 microns in diameter. We have successfully overcome many of the problems encountered; in particular, we have eliminated distortion effects in the immediate vicinity of the filaments, so that angles can be measured reliably. The spatial angles of tracks emerging from the wires as well as their ranges are determined and appropriate corrections are made for the uncertainty in the energy measurement due to the unknown amount of energy dissipated during the traversal of the wire. Data from exposures to a hardened neutron beam from the Harvard 95-in. synchrocyclotron will be compared with equivalent exposures of unloaded plates.

* This work was supported by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
[1] R. W. Waniek and Taiichiro Ohtsuka, Phys. Rev. **91**, 1574 (1953).
[2] R. W. Waniek and Taiichiro Ohtsuka, Phys. Rev. **89**, 1307 (1953).
[3] G. P. S. Occhialini, Nuovo cimento **8**, 341 (1951).

LA10. Variable Mercury Delay Line Equipment for the Measurement of Short Half-Lives. C. SHEER, A. ZINN, AND N. HARTMANN, *Columbia University.**—An instrument has been developed featuring a variable mercury delay line which is capable of measuring continuously variable time intervals in the range 0.01 to 100 μsec with an absolute error <0.0016 μsec at any point in the range. This range of time intervals is too short for measurement with equivalent accuracy by conventional electronic gate circuits, and too long for convenient measurement by slotted line techniques. The continuous variation is accomplished by means of a mercury acoustic line using quartz crystal transducers where the length of the mercury path between crystals is controlled by an accurately machined feed screw. By the use of Invar alloy in the construction of the line, together with a bellows arrangement, the delay has been rendered virtually independent of ambient temperature. The instrument has been constructed with two channels, each with associated insertion-loss amplifiers. It is possible to measure delayed coincidences very accurately, when the delay times are $\sim$ several μsec or greater, by measuring the coincidence rate between the two channels as a function of relative delay. Application to the measurement of short half-lives will be discussed.

* This work partially supported by the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 10:00

Schermerhorn 501

(HARVEY BROOKS presiding)

Solid-State Physics, II

M1. Viscoelasticity in Complex Static Stress Systems. A. A. MACLEOD, A. R. DIDONATO,* AND A. C. WEBBER, *Du Pont Experimental Station.*—A general method is developed for deriving time-dependent equations which relate stress and strain in complex viscoelastic stress systems. The method is easy to apply and practical. The Boltzmann superposition

principle forms the basis for the analysis whereby viscoelasticity in solids is characterized by two parameters plus the usual elastic constants. Experimental verification is given for a system of clamped beams, torsion of cylindrical bars, flexure of disks, buckling of a column, and pipe under hydrostatic pressure. The materials used were 66 Nylon, 610 Nylon, tetrafluoroethylene resin, polyethylene, molded acrylic resin, and a glass fiber-polyester laminate.

* Central Research Laboratory, Westinghouse Air Brake Company, Melpar Division, Alexandria, Virginia.

M2. Creep and Relaxation of Plastics. A. R. DiDonato,* A. A. MacLeod, and A. C. Webber, *Du Pont Experimental Station.*—The Boltzmann superposition principle given in the form of B. Gross's equations is successfully employed to calculate 1000-hour tensile creep data from ten-hour experimental stress relaxation data for three partially crystalline plastics: 66 Nylon, 610 Nylon, and tetrafluoroethylene resin. A two-parameter empirical function given as $(1+t/b)^{-m}$ is used to represent experimental tensile relaxation data (normalized by the initial stress) and its extrapolation. The calculated expression for creep is asymptotic and valid for times, t, greater than one hour. A discussion of a time-temperature relationship is included in order to justify the extrapolations used. It is shown for materials for which the empirical stress relaxation expression is valid that a simple criterion exists for determining when extrapolations are justified.

* Central Research Laboratory, Westinghouse Air Brake Co., Melpar Division, Alexandria, Virginia.

M3. The Electrical Conduction and Dielectric Properties of Ice.* E. J. Workman and W. Drost-Hansen, *New Mexico Institute of Mining and Technology.*—Ice frozen in an orderly manner from a weak solution of cesium fluoride incorporates substitutionally fluoride ions which facilitate the establishment of electrical domains in the structure. The electrical conductivity along the c-axis of such ice changes over a wide range with the sense and magnitude of an applied field parallel to the c-axis.[1] The effect of temperature is such as to indicate that the applied electric field—dependent upon its direction—further orders or produces disorder of highly coordinated domains within the crystalline matrix. The mechanism of coordination within the domains involves a step-by-step process providing for pronounced hysteresis (conductivity *vs* electric field) and polarization. The contributions to the dielectric constant by the order-disorder processes described above are large, ranging from approximately zero at 10 kc to approximately 100 times the generally accepted value for the static dielectric constant. The domain contribution to the dielectric constant increases sharply with temperature near the melting point, and it vanishes for a sufficiently large superimposed electric field in the nonconductivity direction.

* Supported in part by the U. S. Office of Naval Research.
[1] Truby, Bull. Am. Phys. Soc. **27**, No. 6, p. 21 (1952).

M4. Theory of Volume Rectification in Ice.* W. Drost-Hansen and E. J. Workman, *New Mexico Institute of Mining & Technology.*—The properties of halide-ion contaminated ice samples (approximately 10^{16} impurity centers per cc, see abstract M3) can be understood if one assumes the existence of domains of ordered structure surrounding each impurity center. The dc-rectification phenomenon (front to back ratio $\simeq 1:10^5$) occurs as the result of changes in the wave function describing a linear array of hydrogen-bonded water molecules—partly through the displacement of protons under the stress of the applied field. It is proposed that this may lead to a sudden increase in conductivity through critical variations in internuclear distances (analogous to the suggestion by Mott[1]) and rectification occurs because of the asymmetrical arrangement of the water molecules within the domains. Consistent with this mechanism, the rectifying properties disappear for ac fields of sufficiently high frequency. It is proposed that this mechanism has general application (e.g., may explain the rectifying properties of $BaTiO_3$)[2] and may serve as a guide to predict substances exhibiting volume-rectifying properties.

* Supported in part by the U. S. Office of Naval Research.
[1] Mott, Proc. Phys. Soc. **A62**, 416 (1949).
[2] E. P. Wigner and E. T. Jaynes, Phys. Rev. **79**, 213 (1950). See also D. L. Waidelich, J. Acoust. Soc. Am. **25**, 796 (1953).

M5. The Effects of Stepped Surfaces on the Motional Parameters of Piezoelectric Filter Plates.* Charles R. Mingins, Robert W. Perry, and Albert D. Frost, *Tufts College.*—The relative positions in frequency of the members of the thickness-shear family of modes in a piezoelectric crystal plate can be changed by altering the shape of the major surfaces. Correspondingly, the width of the pass band and its frequency position are changed when the plate is used as a divided-electrode filter.[1] In particular, the pass band can be made wider by cutting steps in the surface of the plate.[2] The motional inductances, capacitances, and resistances effective in such a filter have been measured as the steps were gradually deepened. The parameters associated with the 1,2,1 mode were much more affected than those associated with the fundamental thickness-shear resonance. With this geometry, in contrast to the grooved case, the mechanical effects of elasticity and inertia were masked from the start by the stronger electromechanical effect.

* This work has been sponsored by the U. S. Signal Corps.
[1] Mingins, Perry, and MacLeod, Phys. Rev. **91**, 471 (1953).
[2] McDonough, MacLeod, and Larson, Phys. Rev. **88**, 154 (1952).

M6. X-Ray Study of Prismatic Punching in Thallium Chloride. Edward I. Salkovitz and Paul L. Smith, *U. S. Naval Research Laboratory.*—Smakula and Klein[1] have investigated the strain patterns produced in thallium halide crystals under pressure of a cone perpendicular to the crystal surface. They describe a "superficial" pattern consisting of radial wings about the press point and a "transmitted" pattern consisting of a raised prism on the opposite side of the press point. With a simple pressing device, we have been able to push a prism of square cross section (about 2 mm on a side) nearly through a single crystal disk 2 mm thick. Since the load was applied normal to the (001) plane in the (100) direction, the "superficial" pattern showed fourfold symmetry when viewed between crossed polaroids. Grazing angle x-ray patterns showed a mosaic-block like structure within the radial wings. X-ray patterns from the walls of the prism showed asterism only in the direction of glide. Patterns from the cavity left by the extruded prism in the parent crystal were very similar in appearance. When the disk was annealed at 275°C for two weeks and then cooled at the rate of $1\frac{1}{2}$°/hr, no recrystallization occurred. This would be in keeping with the dislocation model for prismatic punching as discussed by F. Seitz. The mosaic-structure in the radial wings, however, seemed to have been frozen in.

[1] A. Smakula and M. W. Klein, J. Opt. Soc. Am. **39**, 445 (1949).

M7. On the Electric Breakdown of Crystals in the High-Temperature Region. Kurt Lehovec, *Sprague Electric Company.*—At fields smaller than Von Hippel's breakdown field F_0^*, there exists an energy region ("energy barrier") where electrons lose energy on the average. Seitz[1] has discussed the chance of an individual electron's crossing this energy barrier by random processes. I shall discuss an alternate approach based on the diffusion in wave-vector space arising from the distribution function of electrons over energy states. My considerations suggest for the breakdown field F^* $F^{*2} \approx F_0^{*2} - 3mkT|\langle \partial\epsilon/\partial t\rangle|/(2e^3\epsilon\tau)$, where m equals electron mass; ϵ, electron energy; $\langle \partial\epsilon/\partial t\rangle$, average energy change per unit time due to collisions; τ, transport collision frequency: these values are taken for the peak of the energy barrier. Since F_0^{*2} increases with T, whereas

the following term decreases with T^3, the observed maximum of the breakdown field with temperature is explained.

[1] F. Seitz, Phys. Rev. **76**, 1376 (1949).

M8. Self Diffusion in KCl.* J. F. ASCHNER, *University of Illinois.*—The self-diffusion coefficient, D, of the potassium ion, K^+, in single crystals of KCl has been measured over the temperature range from 500°C to 700°C by the use of radioactive K^{42}. The electrical conductivity of the crystals was also measured by means of an ac bridge. The conductivity, σ_+, resulting from the potassium ion was calculated by combining the conductivity data and the transference number data of Kerkhoff.[1] Over the temperature range investigated, the Einstein relation $\sigma_+/D = Ne^2/kT$ is satisfied. N is the number of potassium ions per unit volume, and the other symbols have their usual significance. This result is in disagreement with the data of Witt,[2] who found a deviation from the Einstein relation in KCl. There appears to be no direct experimental evidence for the existence of vacancy pairs in KCl, as suggested by the theoretical work of Dienes.[3]

* Work supported in part by the U. S. Office of Naval Research.
[1] F. Kerkhoff, Z. Physik **130**, 449 (1951).
[2] H. Witt, Z. Physik **134**, 186 (1953).
[3] G. J. Dienes, J. Chem. Phys. **16**, 620 (1948).

M9. Tunneling of Electrons in Alkali Halides.* D. L. DEXTER, *University of Rochester.*—The tunneling of electrons from F centers to hole centers is calculated for the ground and excited states, and the accompanying bleaching is discussed. Tunneling ranges of 30 and 40A are found, corresponding to saturation concentrations of about 10^{19} per cm^3 if the F- and V-center distributions interpenetrate. The effect of an electric field is examined, and applications of the theory are made to experiments by Maurer and co-workers on optical and thermal bleaching in the presence of a field. Implications are discussed of tunneling phenomena on the x-ray coloration of crystals at low temperatures, and it is concluded that tunneling represents an important back-reaction for limiting local color-center concentrations.

* Research supported in part by the U. S. Air Force.

M10. Color Centers in KCl Crystals Produced by High-Energy Protons. W. LEIVO AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—Single crystals of potassium chloride were irradiated with 400-Mev protons from the Carnegie Institute of Technology synchrocyclotron. The absorption bands produced in the crystal were measured in the range 250 to 1000 mμ. Bands corresponding to F, M, R_1, R_2, and V centers were observed with a slight indication of other centers and a growth of the R bands upon bleaching was noted. No bands resulting from color centers that are not produced by x-rays were found. The absorption measurements were made with a Beckman Model DU spectrophotometer equipped with a photomultiplier attachment. Since the crystals are radioactive after irradiation, a quartz shield was placed between the crystals and the phototube to stop β rays. Under the conditions of the experiment the γ activity was negligible. To prevent undue heating of the crystals during irradiation, the crystals were enclosed in an aluminum capsule filled with helium. The temperatures during irradiation, however, may still be over 200°C. The absorption measurements were made at room temperature. Work is in progress to irradiate and measure the absorption bands of the crystals at liquid helium temperatures.

FRIDAY MORNING AT 10:00

Horace Mann

(M. W. ZEMANSKY presiding)

Cryogenics

Invited Papers

N1. Critical and Supercritical Flow of Liquid Helium II. J. G. DASH, *Los Alamos Scientific Laboratory.* (20 min.)

N2. Recent Studies of the Heat Capacities of the Superconducting Elements. H. A. BOORSE, *Columbia University.* (30 min.)

Contributed Papers

N3. Theory of Temperature Waves. PAUL M. MARCUS, *Carnegie Institute of Technology.*—Periodic variation of the temperature or heat flux at the boundary of a cylindrical rod produces propagating waves of temperature with well-defined but complex propagation constants. Such waves can be reflected at discontinuities and analyzed into modes; the lowest mode generally has much the lowest attenuation. A rigorous description in transmission line language is possible and useful, with voltage taken analogous to temperature and current to heat flux; lumped circuits then represent discontinuities (neglecting higher mode interactions between discontinuities). A circuit representation requires reciprocity, imposing a condition on the characteristic impedances of different rods meeting at a junction. The thermal impedance of any obstacle must be resistive and capacitative but can never be inductive, hence, resonant effects never occur, as might be expected from the diffusion origin of the waves. In fact, temperature waves carry neither energy nor momentum, in contrast to "higher" types of waves, e.g., acoustic which carry energy but not momentum, electromagnetic which carry both, hence, must be described as just propagating disturbances. Calculations on the single series impedance of the change of cross section and material in circular rods have been made by variational methods.

N4. Structure of Liquid Helium by X-Ray Scattering.* W. L. GORDON,† C. H. SHAW, AND J. G. DAUNT, *Ohio State University.*—The intensity scattered from liquid helium as a function of angle between 2° and 90° and as a function of temperature between 1.4°K and 4.2°K has been obtained

using counter registration. The liquid helium sample was contained in a thin-walled beryllium tube mounted directly over the axis about which the detector arm, with its proportional counter and slit system, rotated. A differential filter of Ni and Co foils was used for monochromatization of the Cu $K\alpha$ radiation from a Machlett diffraction tube operated at 40 kv and 15 ma. The operation of this filter was improved by use of a pulse-height analyzer adjusted to accept pulses from Cu $K\alpha$ radiation in the xenon-filled proportional counter, reducing both background and mismatch error in the filter. The angular resolving power was approximately one-half degree. A single intense diffraction peak was observed at 28° where the counting rate was 2000 cpm, of which about 1900 cpm were coherently scattered. At the time of writing, it appears that there are no other peaks with an intensity greater than three percent of the one above at either 1.4 or 4.2°K.

* Supported by a Research Corporation grant.
† General Electric Coffin Fellow, 1952–1953.

N5. Critical and Supercritical Flow in Liquid Helium II. JAY GREGORY DASH, *Los Alamos Scientific Laboratory.*—An empirical theory of superfluidity and dissipative processes peculiar to He II has been developed from the assumption of phonon excitation by large numbers of cooperating superfluid atoms in motion relative to a solid wall immersed in the liquid. Energy conservation and the independence of the velocity fields of normal and superfluid fractions lead to the energy dissipation $E_f=0$ for superfluid velocities v_s smaller than critical, and $E_f \alpha \rho_s(v_s^2-v_c^2)$ for all $v_s>v_c$. The magnitude of v_c is established by the liquid dimensions, which specify the wavelength, and, hence, the energy of the weakest phonons that may be excited: the functional dependence is given as $v_c \alpha (\rho_s d)^{-1}$, where d is the characteristic dimension of the liquid. The predictions of the theory are compared with a large body of experimental data. Experiments in the dissipative velocity region appear to be more in accord with the present theory than with the theory of mutual friction of Gorter and Mellink. Correlation with critical velocity values observed over a range of d of six decades closely follows the present prediction, in contrast to the dependence arising from considerations of the uncertainty principle.

N6. The Role of Substrate and Surface Finish in Helium II Film Transport.* B. SMITH AND H. A. BOORSE, *Columbia University.*—An improved version of the high-frequency electrical technique[1] was used to investigate transport over copper, silver, nickel, aluminum, strainless steel, nickel-silver, and precision-bore Pyrex beakers of 5.8 cm internal depth. Measurements of transport over the latter four metals were made not only over the original *machined* surfaces,[2] but also after *superfinishing*[3] by the Chrysler Corporation. Transport rates were remeasured after superfinishing the *external* surfaces and again after *internal* superfinishing. Ground, as well as untreated Pyrex surfaces, were also studied. The results will be analyzed not only with respect to (*A*) the role of substrate and *measured* microfinish, but also with respect to (*B*) the variation of the functional dependence on temperature of the various transport rates with substrate, surface finish, and height, and (*C*) the variation of height dependence with temperature, substrate, and microfinish.

* Assisted by the U. S. Office of Naval Research and Linde Air Products.
[1] J. G. Dash and H. A. Boorse, Phys. Rev. **82**, 851 (1951).
[2] B. Smith and H. A. Boorse, Phys. Rev. **92**, 505 (1953).
[3] A. M. Swigert, *The Story of Superfinish* (Lynn Publishing Company, Detroit, 1940).

N7. The Low-Temperature Oscillatory Hall Effect.* J. S. LEVINGER AND E. G. GRIMSAL, *Lousiana State University.*—Oscillations in the Hall voltage for bismuth may exist[1] at 14°K, and are shown clearly in Reynold's measurements[2] at liquid helium temperatures. We shall present calculations of Hall effect oscillations at 0°K based on a crude model, and we shall compare with Reynold's results. We use an isotropic two-band model for the Hall effect, as a preliminary crude approximation. The number of ordinary conduction electrons is independent of H, while that of the "de Haas-van Alphen electrons" oscillates, as shown by Peierls, Blackman,[3] and others. This model, choosing values of the effective masses and Fermi energy of the same order of magnitude as Blackman's values, gives oscillations similar to those observed by Reynolds. We shall also present the results of calculations now in progress on the effect of temperature in smearing out the oscillations.

* Supported in part by the National Science Foundation.
[1] Gerritsen, de Haas, and van der Star, Leiden Comm. No. 2656 (1942). L. C. Brodie, Bull. Am. Phys. Soc. **28**, No. 6, 31 (1953).
[2] Reynolds, Leinhardt, and Hemstreet (letter submitted to Phys. Rev.).
[3] M. Blackman, Proc. Roy. Soc. (London) **A116**, 1 (1938).

N8. Neutron Diffraction Investigations on Superconducting Elements. M. K. WILKINSON, C. G. SHULL, L. D. ROBERTS, AND S. BERNSTEIN, *Oak Ridge National Laboratory.*—Neutron diffraction investigations have been made on several superconducting elements to determine if the electronic ordering, which presumably accompanies the formation of the superconducting state, causes changes in the neutron diffraction patterns. Data were taken at temperatures of 4.1°K and at 20.4°K for vanadium, lead, and niobium, which have superconducting transition temperatures of 4.7°K, 7.2°K, and 8.7°K, respectively. With the samples at the lower temperature, no extra coherent scattering features were observed, either at new positions or superimposed on the normal Bragg nuclear scattering reflections, and there were no measurable changes in the diffuse scattering which could be attributed to the transition to the superconducting state. A study of the lattice characteristic temperatures was also made from the nuclear Bragg reflections on the Nb patterns to see if the large changes, which have been measured in specific heat variation above and below the superconducting transition, could be accounted for by changes in lattice vibration effects. The neutron scattering data suggest that there is no pronounced change in the atomic lattice vibrations of Nb when it becomes a superconductor.

N9. Compressibilities of Solid Hydrogen and Deuterium at 4.2°K. J. W. STEWART AND C. A. SWENSON,* *Harvard University.*—The compressibilities of solid hydrogen and deuterium have been determined at 4.2°K. Preliminary extrusion experiments showed that these solids are quite plastic and, hence, themselves approximate transmitters of hydrostatic pressure. Pressure is applied directly to the samples with a stainless steel piston and the displacement observed. The apparatus can exert up to 4000 kg/cm². For hydrogen, the compressibility $[-1/V_0(\partial V/\partial P)]$ is $(5.0\pm1)\times10^{-4}$ cm²/kg at zero pressure and $(0.72\pm0.05)\times10^{-4}$ at 1800 kg/cm². For deuterium, the values range from $(4.0\pm1)\times10^{-4}$ at zero pressure to $(0.56\pm0.05)\times10^{-4}$ at 1800 kg/cm² and $(0.42\pm0.05)\times10^{-4}$ at 2800 kg/cm². As compared with other solids, the decrease of compressibility with pressure is abnormally rapid for both H_2 and D_2. The present results agree satisfactorily with previous work at zero pressure.[1] At higher pressures our solid samples suddenly collapse; hydrogen more readily than deuterium. The exact pressure at which this collapse (probably melting of the solid) occurs is not reproducible. Various possible causes for this "catastrophe" have been considered.

* Now at Cryogenic Engineering Laboratory, M. I. T.
[1] H. D. Megaw, Phil. Mag. **28**, 139 (1939).

FRIDAY MORNING AT 10:00

Harkness Academic Theatre

(H. A. BETHE presiding)

Symposium on Nuclear Size and Density Distribution

O1. Diffraction Scattering of 22-Mev Protons. B. L. COHEN, *Oak Ridge National Laboratory.* (30 min.)

O2. Nuclear Determinations from Electron Scattering. ROBERT HOFSTADTER, *Stanford University.* (30 min.)

O3. Nuclear Size from Mesonic Atoms. JAMES RAINWATER, *Columbia University.* (30 min.)

O4. Nuclear Size from X-Ray Fine Structure. C. H. TOWNES, *Columbia University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

McMillin Theatre

(H. A. BETHE AND P. E. KLOPSTEG presiding)

Joint Ceremonial Session of the APS and the AAPT

Retiring Presidential Address of the American Physical Society

P1. What Can We Learn with High-Energy Accelerators? ENRICO FERMI, *University of Chicago.*

Presentation of the Oersted Medal of the AAPT

Response of the Oersted Medallist

P2. The Metaphysics of a Physics Teacher. C. N. WALL, *University of Minnesota.*

Twelfth Richtmyer Memorial Lecture of the AAPT

P3. Fields and Particles. J. A. WHEELER, *Princeton University.*

FRIDAY AFTERNOON AT 3:30

Pupin 301

(WALTER GORDY presiding)

Group of Papers from North Carolina Scheduled Together by Special Request

PA1. An Improved Apparatus for High Resolution Neutron Cross-Section Measurements.* J. H. GIBBONS, *Duke University.*—A neutron collimation-detection system,[1] designed to measure total neutron cross sections with high resolving power and reasonable counting rates (10^3 to 10^4 counts per minute) has been improved in stability, resolution, and energy calibration. A troublesome background counting rate has been identified as mainly resulting from forward-angle neutrons scattered in the tantalum target backing. Approximate correction factors have been determined. A cylindrical electrostatic analyzer is now being used for both proton energy calibration and beam resolution. Neutrons are obtained from the Li(p,n) reaction. Neutron monitoring at 0° appears to be quite satisfactory for our geometry. Resonances have been observed at neutron energies as low as 270 ev; however, background corrections are quite appreciable below 4 kev. Hence

the optimum energy region for investigation with this system begins at about 4 kev. The resolving power decreases with increasing neutron energy, amounting to about 0.5 kev at 5 kev, 1 kev at 12 kev, 2 kev at 30 kev, and 3 kev at 60 kev. Results of some of the cross-section measurements will be shown.

* Work supported by the U. S. Atomic Energy Commission.
[1] J. H. Gibbons and H. W. Newson, Phys. Rev. **91**, 209(A) (1953).

PA2. Total Neutron Cross Sections in the Kilovolt Region: As, Zr, Nb, La, Ce, Pr, and Au.* R. C. Block and J. H. Gibbons, *Duke University*, E. G. Bilpuch and D. F. Herring, *University of North Carolina*.—Zr has resonances at 4.5, 7.5, 14, 20, 24, and 28 kev and many higher energy resonances which are only partially resolved; two which are particularly strong lie at 45 and 75 kev. Ce has one very strong resonance at 24 kev which must be due to Ce^{140} (88 percent) and 10 more much weaker ones between 5 and 50 kev. Some of the weaker peaks overlap the strong one and are probably attributable to Ce^{142} (11 percent). Pr and La each appear to have two distinct resonances below 1.5 kev, but none are resolved at higher energies. The average spacings must be $\sim$1 kev per J value. The cross-section curves of As and Nb show evidence of partially resolved resonances; the average spacings must be <1 kev. Au shows few signs of resonance structure down to 0.6 kev; the average spacing must be $\ll 1$ kev.

* Work supported by the U. S. Atomic Energy Commission.

PA3. Total Neutron Cross Sections in the Kilovolt Region: Cu, Cu^{63}, Cu^{65}, and Ga.* H. Marshak, *Duke University* (introduced by H. W. Lewis).—The total neutron cross sections of Cu, Cu^{63}, Cu^{65}, and Ga between 1 and 55 kev were measured with the equipment just described. The Cu^{63} and Cu^{65} samples were 99.4 percent and 98.2 percent pure, respectively.[1] The Cu sample showed resonances at 2.5, 6, 8.5, 11.5, 15, 19, 22, 26.5, 31, 35.5, and 44 kev. The 8.5- and 19-kev resonances are a result of Cu^{65} whereas the 15-, 26.5-, and 35.5-kev resonances show up about the same in both enriched samples; the remaining resonances are a result of Cu^{63}. Since, in general, resonance transmission is not exponential, experiments are being performed to measure the effect of the small isotopic contaminations in the samples. There were also weaker resonances at 3, 5, 41, 44, and 49 kev found only in Cu^{65}. The average level spacing per J value is about 12 kev in Cu^{64} and probably considerably less in Cu^{66} since the resonances in the latter are weaker and less well resolved. The 300-ev resonance in Ga was observed, but no other resonances were well resolved.

* Work supported by the U. S. Atomic Energy Commission.
[1] Loaned by the Isotopes Division, U. S. Atomic Energy Commission.

PA4. Total Neutron Cross Sections in the Kilovolt Region: Li, F, Cl, Sc, Rb, Mo, Ag, and Ta.* J. R. Patterson, H. W. Newson, and R. C. Mobley,† *Duke University*, T. E. Gilmer, *University of North Carolina*.—No new resonances were found in Li and F between 1 and 80 kev. Resonances were found in Sc at 5, 10, 13, 15(?), 22, 34, 72, and 81 kev; the average spacing per J value is 10 kev below 25 kev. There appear to be a number of partially resolved levels below 80 kev. Rb has resonances at 5 and 10 kev and a number of partially resolved levels below 25 kev. Resonances were observed in Cl at 8, 26, 120, and 160 kev; weaker resonances are also present. Separated isotopes will be used to obtain level spacing information on Cl and Rb. Weak resonances appear in the cross section curve for Mo. Ag and Ta show almost no resonance effects in their cross-section curves and evidently have level spacings $\ll 1$ kev. The upper limits are in accord with low energy data.[1] Average spacings are calculated only when there appears to be a reasonable chance that a majority of the resonances have been resolved.

* This work was supported by the U. S. Atomic Energy Commission.
† Now at Louisiana State University, Baton Rouge, Louisiana.
[1] U. S. Atomic Energy Commission U-2040.

PA5. Total Neutron Cross Sections in the Kilovolt Region: Se, Br, Y, I, and Cs.* H. W. Newson, R. M. Williamson, A. L. Toller, and P. F. Nichols, *Duke University*.—Se has resonances at 3, 7, 21, 32, 35, 46, 52, and 62 kev. The first two have been shown by activation measurements to result from Se^{80} (48 percent abundant). Most of the other resolved resonances should probably be attributed to this predominant isotope. On this assumption the average spacing of Se^{81} is about 9 kev. Y has resonances at 8.5, 12.5, 18(?), 25(?), 31, 56, 58, 64, and 71 kev. There are other resonances between 36 and 50 kev, but this region must be remeasured. One or two weak resonances may be present between 3 and 6 kev, but no others are evident down to 0.75 kev. The average level spacing is about 12 kev per J value. Variations in the cross section curves of Br, I, and Cs have been observed below a few kilovolts, but we have been unable to obtain clearly resolved resonances in any of them. The average level spacings must be <1 kev. Nuclear shell effects and other factors which appear to influence nuclear levels will be discussed.

* This work was supported by the U. S. Atomic Energy Commission.

PA6. (p,γ) Coincidence Measurements Utilizing Proton Time-of-Flight.* W. T. Joyner, *Duke University* (introduced by H. W. Lewis).—For use in angular correlation measurements between charged particles and gamma rays, a fast coincidence circuit similar to that described by De Benedetti[1] has been developed to select proton groups by virtue of their time-of-flight. A thin terphenyl crystal served as the proton detector at a distance of one meter from the target; a thick stilbene crystal was used as the gamma detector. Each crystal was mounted on a DuMont 6292 photomultiplier. The reaction $Al(p,p'\gamma)$ has been observed with the apparatus. The curve of coincidence rate *vs* delay for a 2.33-Mev proton has a full width at half-height equivalent to 0.5 Mev. The ratio of the true coincidence rate to the accidental coincidence rate is about ten for a 0.1 microampere beam current onto a 55-kev aluminum foil, with coincidences involving elastic protons suppressed by an anticoincidence circuit. Slides showing coincidence rate *vs* time delay will be shown, and the apparatus will be described.

* This work was supported by the U. S. Atomic Energy Commission.
[1] S. De Benedetti and H. J. Richings, Rev. Sci. Instr. **23**, 37 (1952).

PA7. Production of L-Shell X-Rays by Protons.* Eugene Bernstein, *Duke University* (introduced by H. W. Lewis).—The cross sections for L-shell x-ray production by 2- to 4-Mev protons on several heavy elements have been measured. The NaI scintillation apparatus was similar to that used earlier for K-shell measurements,[1] but improvements essential to the detection of the softer x-rays have been made. The use of thin windows, of a thin scintillator for background reduction, and of the high resolution Dumont 6292 phototube have made it possible to obtain well-resolved pulse-height peaks for the L x-rays between Ta (9 kev) and U. In contrast to the E^4 dependence on proton energy for K-shell ionization, the L-shell dependence for Ta is near $E^{1.8}$. The ratio of the cross sections for L and K ionization of Ta, corrected for the Auger effect, is between 10^3 and 10^4, depending on proton energy. The total thick target yield of L x-rays per proton from Ta at 2.40 Mev is 4×10^{-4}. The cross section at 2.4 Mev for Ta-L ionization is about 300 barns. Results on other elements will be discussed.

* Work was supported by the U. S. Atomic Energy Commission.
[1] Lewis, Simmons, and Merzbacher, Phys. Rev. **91**, 943 (1953).

FRIDAY AFTERNOON AT 3:30

Schermerhorn 501

(J. B. H. KUPER presiding)

Group of Papers from Brookhaven Scheduled Together by Special Request

PB1. Estimation of Beam Intensity and Cross Sections at the Cosmotron from the Gross Radioactivity in Copper.* ANTHONY TURKEVICH,† *Brookhaven National Laboratory.*—The gross beta activity of thin copper foils bombarded with 2.2-Bev protons, varies approximately as $T^{-1.18}$ in the interval $0.8\text{ hr} \leq T \leq 800\text{ hr}$. Copper bombarded with 0.45-Bev protons shows only slightly larger deviations from this power law. This similarity pertains despite large changes in the relative contributions of some important radioactive nuclides.[1] The number of radioactive disintegrations measured in the stated time interval is assumed to be the same fraction of the total number of nuclear interactions in the targets at the two energies. At 0.45 Bev, the cross section for the production of the radioactive species in question is determined to be 50 mb via the known $Al^{27}(p,3pn)Na^{24}$ cross section of 10.8 mb[2]. At the higher energy the corresponding gross activation cross section is assumed to be 60 mb (because of decreased nuclear transparency). This method leads to typical proton intensities of 3×10^{10} per burst in the Cosmotron (summer 1953), and to cross sections of 9 mb for the $Al^{27}(p,3pn)Na^{24}$ reaction and 6 mb for the formation of Cu^{64} from copper with 2.2-Bev protons. It is felt that these numbers are good to about 50 percent.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Institute for Nuclear Studies, University of Chicago, Chicago 37, Illinois.
[1] Friedlander, Baker, Hudis, Miller, and Wolfgang, abstract PB4.
[2] L. Marquez, Phys. Rev. **88**, 225 (1952).

PB2. Reactions of Aluminum with 2.2-Bev Protons.* J. HUDIS, R. WOLFGANG, N. SUGARMAN,† AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—Cross sections for the formation of radioactive products resulting from 2.2-Bev proton bombardment of aluminum have been determined. The values for Na^{24}, F^{18}, C^{11}, and N^{13} were obtained by analysis of gross decay curves. The Be^7/Na^{22} ratio was found by scintillation spectrometer measurements of the gamma-ray intensities of chemically separated sodium and beryllium fractions. Na^{22}/Na^{24} ratios were also determined on separated sodium samples. The absolute cross sections listed are based on the measurements of proton beam intensity described in the preceding abstract by A. Turkevich and may therefore be in error by as much as ±50 percent. The relative values should be good to ±20 percent. The cross sections for C^{11} and Be^7 formation are about 2.5 and 11 times larger than the corresponding cross sections at 335-Mev proton energy[1] while the other cross sections are roughly the same at the two energies. The use of Na^{24} activity induced in aluminum foils for monitoring proton beam intensities will be discussed.

	Na^{24}	Na^{22}	F^{18}	N^{13}	C^{11}	Be^7
σ(mb)	9.0	8.3	5.4	~1.5	5.1	16

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Institute for Nuclear Studies, University of Chicago, Chicago, Illinois.
[1] L. Marquez and I. Perlman, Phys. Rev. **81**, 953 (1951).

PB3. Momentum Transfer in High-Energy Nuclear Interactions in Aluminum.* R. WOLFGANG AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—The recoil of Na^{24}, F^{18}, and C^{11} out of aluminum foils struck by 0.6- to 2.2-Bev protons has been studied. The experimental techniques used were essentially similar to those employed by Si-Chang Fung and Perlman[1] in a corresponding study at lower energies. The total loss of Na^{24} from a 0.25-mil foil is 16.3 percent at 0.6 Bev and this value decreases slowly to 14.0 percent at 2.2 Bev. Similarly, the recoil losses of F^{18} and C^{11}, although greater than that of Na^{24}, seem to be roughly constant between 0.6 and 2.2 Bev. A small and approximately constant recoil loss in the backward direction was observed in all cases. Relstivistic momentum considerations predict the slow, apparently asymptotic, decrease observed for Na^{24} recoils, if it is assumed that Na^{24} formation corresponds to the transfer of a constant amount of excitation independent of bombarding energy. This assumption thus appears to be valid for light nuclei up to energies of 2.2 Bev. In this connection the approximate constancy of the Na^{24} formation cross section with energy reported in the preceding paper is of interest.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Si-Chang Fung and I. Perlman, Phys. Rev. **87**, 623 (1952).

PB4. Radioactive Products from the Interaction of 2.2-Bev Protons with Copper.* G. FRIEDLANDER, E. BAKER, J. HUDIS, J. M. MILLER, AND R. WOLFGANG, *Brookhaven National Laboratory.*—Formation cross sections will be reported for approximately 40 radioactive nuclides produced in the interaction of copper with 2.2-Bev protons. Within about 10 mass units of copper the cross sections are somewhat lower than those observed with 340-Mev protons.[1] However, for lighter products the rapid drop-off in yields with decreasing mass number which is observed at 340 Mev is not found at the higher energy. In fact, the cross sections stay substantially constant over the whole mass range. The ratio of cross sections for pairs of isobars appears to be roughly constant with bombarding energy, even in cases where the cross section for forming the particular mass number is rather energy sensitive.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Batzel, Miller, and Seaborg, Phys. Rev. **84**, 671 (1951).

PB5. Production of Gallium, Germanium, and Arsenic Nuclides by 2.2-Bev Protons on Copper.* NATHAN SUGARMAN† AND ANTHONY TURKEVICH,† *Brookhaven National Laboratory.*—Radiochemical isolation of Ga, Ge, and As from copper bombarded with 2.2-Bev protons led to yield determinations (in millibarns) for the following nuclides: Ga^{66}, 0.04; Ga^{67}, ~0.06; Ga^{68}, 0.04; Ge^{69}, 0.01; As^{71}, 0.0002; As^{72}, 0.0002. Yields for 340-Mev protons on copper[1] are about one-fourth as high for Ga isotopes and about one-tenth for Ge. No As yields were reported at the lower energy. These Ga, Ge, and As nuclides are interpreted as being formed by reactions of the type $Cu(Z,xn)$ with Z being a He, Li, or Be nucleus formed in the primary interactions. The decreased production of Ga, Ge, and As in thin targets results in estimates of the cross sections for the production of these secondary reacting particles and their average energies. These values are: He, 0.3 barn, 32 Mev; Li, 0.01 barn, 40 Mev; Be, ~0.01 barn, ~30 Mev. The larger yields of Li and Be at 2.2 Bev as compared with 340 Mev are consistent with direct radiochemical observations[2] on low mass nuclides.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Institute for Nuclear Studies, University of Chicago, Chicago 37, Illinois.
[1] Batzel, Seaborg, and Miller, Phys. Rev. **84**, 671 (1951).
[2] Friedlander, Baker, Hudis, Miller, and Wolfgang, preceding abstract.

PB6. Disintegration of Heavy Elements by 2.2-Bev Protons.* ROBERT B. DUFFIELD† AND NATHAN SUGARMAN,‡ *Brookhaven National Laboratory.*—The cross sections for a number of nuclear reactions produced in heavy element targets (Bi, Au, Ta) by 2.2-Bev protons have been determined by examination of the radioactive products. The cross sections decrease as the number of nucleons ejected increases, but are still appreciable (a few millibarns) for reactions involving the loss of as many as 60 nucleons. Recoil energy measurements indicate that such reactions (product $Z>55$) probably occur by nucleon evaporation rather than fission. The radioactive nuclei found are more neutron deficient than those made by 450-Mev protons on bismuth. The known alpha-emitting isotopes of the rare earth elements are produced with good cross sections.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

† On leave from University of Illinois.

‡ Permanent address: Institute for Nuclear Studies, University of Chicago, Chicago, Illinois.

FRIDAY EVENING AT 7:00

Grand Ballroom, Hotel New Yorker

(ENRICO FERMI AND P. E. KLOPSTEG presiding)

Banquet of the American Physical Society and the AAPT

After-dinner speakers: **President Grayson Kirk** of Columbia University, **L. Brillouin,** and **S. A. Korff.**

Presentation of Buckley Prize

SATURDAY MORNING AT 10:00

McMillin Theatre

(H. A. BETHE presiding)

Physics at Columbia University: a Programme in Celebration of the Bicentennial of the University

Q1. Physics at Columbia University: the Early Years. G. B. PEGRAM, *Columbia University.* (30 min.)

Q2. Physics at Columbia University: the Genesis of the Nuclear-Energy Project. ENRICO FERMI, *University of Chicago.* (40 min.)

Q3. Physics at Columbia University: the Recent Years. I. I. RABI, *Columbia University.* (40 min.)

Q4. The American Physical Society at Columbia University. K. K. DARROW, *Bell Telephone Laboratories.* (20 min.)

Presentation of a plaque to commemorate the foundation of the American Physical Society at Columbia University on May 20, 1899

SATURDAY MORNING AT 9:45

Pupin 301

(R. L. SPROULL presiding)

Luminescence; Electron Physics

QA1. X-Ray Induced Luminescence in MgO. ALBERT S. EISENSTEIN, *University of Missouri.*—X-ray irradiation of MgO single crystals stimulates luminescent bands at 5.2, 3.6, and 3 ev, as well as an increasing intensity below 2 ev. The 5.2-ev band is increased in intensity by three orders of magnitude with Mg doping and is reduced in intensity with O doping. A photon counter (1*P*28 photomultiplier operated at 90°K) is used to study this luminescence and its subsequent decay following the irradiation. The 5.2-ev band decays rapidly, but the 3.6-ev band intensity falls slowly, approximating a power law with $n=-0.5$. Phosphorescence at 3.6 ev resulting from a dose of 1000 roentgens, delivered in 2 minutes, may be followed for six months. When approximately one-half of the total number of photons to be released are emitted, n increases, approaching -3. An electrical conductivity was found to accompany this phosphorescence but its decay was always more rapid than the luminescent decay. Thermal release of trapped holes followed by hole capture of trapped electrons may account for this long-time luminescence.

QA2. The Luminescence of Beryllium Oxide.* H. O. ALBRECHT AND C. E. MANDEVILLE, *Bartol Research Founda-*

tion.—Under cathode-ray and heavy ion bombardment, beryllium oxide was described by Sir William Crookes as having "a beautiful blue phosphorescence." A preliminary survey of western publications[1] has shown that although BeO has been used frequently as a constituent in silicates and other phosphors, no detailed studies of the luminescent properties of "pure" unactivated BeO appear to have been described. It has recently been observed by the writers that when powdered BeO is irradiated by polonium alphas, fluorescence occurs in a broad emission band, extending from ~2000A to 4000A and above. A tremendous light yield is obtained in the deep ultraviolet ($2000A < \lambda < 3000A$), rivaling and sometimes exceeding that of silver-activated sodium chloride. A faint long period phosphorescence was excited by a Tesla discharge at an air pressure of ~10 microns. This effect was enhanced many fold by heating the pure BeO to 1400°C in atmospheric air. The heat-treated material gives a very intense long-period ultraviolet phosphorescence. BeO is in general less luminescent under hydrogen-arc excitation than are the activated alkali halides.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] The literature of the Soviet Union and associated nations has not been thoroughly searched.

QA3. Electroluminescence in ZnS Single Crystals. W. R. Watson, J. J. Dropkin, and A. T. Halpin, *Sylvania Electric Products, Inc.*—Half-wave voltage excitation resolves the electroluminescent emission of some ZnS single crystals into two processes. At low peak voltages the emission was delayed with respect to the voltage as follows: voltage increasing—no emission; voltage decreasing—emission rising with maximum about voltage zero; voltage off—decay of emission. At higher peak voltage an emission in phase with the applied voltage was also present and increased with rise of peak voltage faster than the delayed emission. Both emissions appeared to originate from the same regions of the crystal but showed different spectral characteristics. Among the secondary effects observed was the quenching of the delayed emission by the increasing voltage of the subsequent half-cycle. The delayed emission, in-phase peak, and quenching are discussed in terms of a picture in which ionization occurs in a localized region of the crystal: charge separation, trapping, release from traps, and recombination under the action of a polarization field are used to discuss the delayed emission and quenching, whereas immediate recombination when higher levels of ionization density are reached account for the in-phase emission.

QA4. Theory of Electroluminescence of Zinc Sulfide Crystals. William W. Piper and Ferd E. Williams, *General Electric Research Laboratory.*—Data on the electroluminescence of single crystals of copper-activated zinc sulfide can be explained quantitatively by the mechanism proposed by Piper and Williams.[1] Conduction electrons with several volts of kinetic energy excite the activator system directly by inelastic collisions or indirectly by impact ionization of valence electrons to form electron-hole pairs which are captured by the activator system. The conduction electrons acquire their kinetic energy in a region of high electric field. The required field is attained in an exhaustion layer at the cathode in the *N*-type semiconductor. The electrons which are accelerated to high kinetic energies are field excited from deep donors. The electroluminescent brightness as a function of applied voltage depends on the distribution in energy of the deep donors, on the field dependence of the probability of accelerating conduction electrons to high kinetic energies, and on the field configuration in the exhaustion layer. Several specific distributions of deep donors have been analyzed. The experimental voltage dependence of brightness and the form of the instantaneous brightness during the voltage cycle are in accord with a continuous distribution in energy of the donor levels.

[1] W. W. Piper and F. E. Williams, Phys. Rev. **87**, 151 (1952).

QA5. Triboluminescence in Crystals.* G. Wolff, *Signal Corps Engineering Laboratories.*—Triboluminescence can be expected where, upon crushing or cleaving of crystals, electrical charges are created on corresponding planes. As a consequence, a glow discharge takes place. In this effect, the presence of a polar axis or the absence of a center of symmetry is of importance. Secondary excited fluorescence, phosphorescence, and surface chemiluminescence can also cause triboluminescence. Relations between permanent triboluminescence and molecular structure, crystal structure, crystal size, and fluorescence will be discussed. In addition, the relation between temporary triboluminescence and lattice distortion will be presented.

* This work is based on experimental data obtained by the author and co-workers at Fritz Haber Inst., Berlin-Dahlem, 1951–1952.

QA6. Photoelectric Emission from BaO.* H. R. Philipp,† *University of Missouri.*—Photoelectric measurements were made on sprayed coatings of BaO. The yield curve showed an exciton rise at 3.8 ev and a rapid rise at 5.0 ev resulting from electrons excited from the occupied band. A magnetic velocity analyzer was used to determine the energy distribution of the emitted photoelectrons. Two peaks in the distribution were observed, one increasing in energy with increasing $h\nu$ and the second occurring at very low energy. The latter peak appeared for values of $h\nu$ above 3.5 ev and did not shift in energy with increasing $h\nu$. The thermionic emission distribution was observed to shift with temperature, and a value for the temperature dependence of the work function calculated from this shift was 3.25×10^{-4} ev/°K. The temperature dependence of the work function calculated from the apparent Richardson A constant was 3.15×10^{-4} ev/°K. Enhancement measurements were made which showed that shorter enhancing wavelengths produce greater increases in photoelectric emission, the relative increase being greater at longer observing wavelengths.

* Supported in part by the U. S. Office of Naval Research.
† Minneapolis Honeywell Research Fellow.

QA7. Effect of Strain on the Work Function of Polycrystalline Silver. G. Wallis* and H. E. Farnsworth, *Brown University.*—Contact potential difference measurements in a pressure range from one atmos to about 10^{-8} mm Hg have indicated that mechanically induced strain of the order of 1 percent (beyond elastic limit) in polycrystalline strips of silver is associated with an increase in work function of between 0.01 and 0.03 ev. Annealing at about 400°C for a period of ten min approximately restores the original value of work function. It is suggested that lattice imperfections induced by the stretching of the strip are responsible for the increase and that their removal during the heat treatment causes the subsequent decrease in work function.

* Socony-Vacuum Fellow. Now with the Electronics Division, Sylvania Electric Company, Ipswich, Massachusetts.

QA8. Energy Losses of Electrons in Passage Through Thin Films.* Lewis B. Leder and L. Marton, *National Bureau of Standards.*—The loss of energy of 30–35 kev electrons passing through thin films of several metals and insulators has been measured using a modified electrostatic electron microscope. The high chromatic aberration of an electrostatic lens with elongated central aperture is used to separate out those electrons which have lost energy.[1] An enlarged image of a 2-micron slit is projected onto a photographic plate, and multiple images are produced by those electrons which have lost energy. These measurements are in the same energy-loss range as those of Mollenstedt,[1] Ruthemann,[2] and others. The materials measured so far are Be, Na, Mg, Al, K, Si, Ti, Fe, Cu, Ge, Pd, Ag, Cd, Sn, Sb, Au, Bi, collodion, and quartz.

The results will be given and discussed in relation to the plasma oscillation theory of Pines and Bohm.[3]

* This work was supported by the U. S. Office of Naval Research.
[1] G. Mollenstedt, Optik **5**, 499 (1949); **9**, 473 (1952).
[2] G. Ruthemann, Ann. Physik **2**, 113 (1948).
[3] D. Pines and D. Bohm, Phys. Rev. **83**, 221 (1951); **85**, 338 (1952).

QA9. Penetration of Medium Fast Electrons into Photographic Emulsions.* L. MARTON AND LEWIS B. LEDER, *National Bureau of Standards.*—As part of the work being done in this laboratory on the inelastic scattering of electrons, measurements were made of the action of electrons passing through photographic emulsions. Lantern Slide medium plates were exposed to the beam of an electron microscope, and exposures at 30, 40, 50, and 60 kev were made in areas on the same plate. The plates were then processed in a conventional manner. With the use of an oil immersion microscope, "optical sectioning" was used to make photomicrographs at 2-micron intervals in depth of the emulsion. This was done for each mono-energetic electron exposure. The developed grains were then counted, and a distribution of the number of grains as a function of depth thereby obtained. The distribution is similar to that found in previous ionization density experiments using higher energies.[1] At those energies the peak of ionization was found to move to greater depths with increasing energy. In the energy range of our experiment, however, the variation of the peaks with voltage appears to be anomalous.

* This work was supported by the U. S. Office of Naval Research.
[1] J. G. Trump and R. J. Van de Graaff, J. Appl. Phys. **19**, 599 (1948); **21**, 345 (1950).

QA10. Propagation of Waves in Ionized Gases. E. P. GROSS, *M.I.T.*, AND M. KROOK, *Harvard University.*—A theoretical study is made of the small-amplitude oscillations of a completely ionized gas as a function of pressure. At low pressures there exist two types of waves. The high-frequency electronic plasma waves[1] are only slightly modified by the motion of positive ions. In addition, we find the low-frequency "plasma-ion" waves previously studied by Tonks and Langmuir.[2] The latter are, however, undamped only when the electron temperature is considerably greater than the ion temperature. To study the effects of collisions we make use of a model for collision processes proposed earlier.[3] It is found that the low frequency modes are increasingly damped as the pressure is raised. The high-frequency modes are also highly damped at intermediate pressure. However, at higher pressures this mode changes its nature continuously and becomes a sound wave with a propagation velocity characteristic of a mixture of gases.

[1] D. Bohm and E. P. Gross, Phys. Rev. **75**, 1851, 1864 (1949).
[2] L. Tonks and I. Langmuir, Phys. Rev. **33**, 195 (1929).
[3] E. P. Gross and M. Krook, Bull. Am. Phys. Soc. (Chicago meeting), **28**, No. 6, 32 (1953), abstract T19.

QA11. Nonuniform Microwave Transmission Lines and Solutions of Riccati Equations. STANLEY WINKLER, *U. S. Naval Material Laboratory.*—The characterization of transmission lines in terms of impedance by a Riccati equation was given by Pierce.[1] Although Riccati equations in general, are not soluble in finite terms,[2] it is possible to obtain such solutions in particular cases.[3] Some of these solutions may be utilized in a discussion of non-uniform transmission lines. Relationships are developed between transmission line distributed parameters and integrability criteria for Riccati equations. This technique is applicable in those cases where the transmission line parameters are continuous functions of the line length. Possible extension of this method may provide an approximation procedure for the solution of transmission lines with discontinuities.

[1] J. R. Pierce, Bell System Tech. J. **22**, 263 (1943).
[2] Joseph Liouville, J. de Math. **6**, 1 (1841); Joseph F. Ritt, Bull. Am. Math. Soc. **33**, 51 (1927).
[3] Stanley Winkler, M. S. thesis, New York University '1950).

QA12. Writing Speed and Tonal Range of Dark Trace Tubes. SEYMOUR NOZICK, *U. S. Naval Material Laboratory* (introduced by Stanley Winkler).—The writing speed of a dark trace tube is shown to be proportional to the ratio of beam current to spot size multiplied by a scotophor sensitivity factor. Experimental verification indicates the magnitude of screen sensitivity. A charge density of 4.37×10^{-4} microcoulomb per square millimeter produces minimum discernible contrast. A minimum of 10.9×10^{7} electrons is required per digit of information. About 10 digits per microsecond can be displayed on the 4AP10 tube face. A high writing speed tube is possible by the optimization of either the ratio of beam current to spot size or the screen sensitivity. The tonal range measured by the number of detectable contrast steps is proportional to the ratio of maximum contrast to spot size. The ability of the eye to discern contrast gradient* modifies this, giving a merit factor for tonal range. Thus an improved tube can be made by the optimization of this ratio. For the 4AP10, the figure of merit is 20. The amount of information which can be displayed can be computed by the raising of the number of possible spots to the tonal range power so that another useful factor is given.

* W. B. Nottingham, *Rad. Lab. Series* (McGraw-Hill Book Company, Inc., New York, 1948), Vol. 22, Chap. 18.

QA13. Errors in Power Spectra Due to Finite Sample.* L. M. SPETNER, *Johns Hopkins University.*—If one measures the power spectrum of Gaussian random noise by selecting a finite sample of this noise, splicing its tail to its head to form an endless loop, and then playing it through a spectrum analyzer, there arise questions of accuracy. Calculations show that the effect of the splice varies with frequency—it is worse for low frequencies than for high, and it also depends upon the frequency at which the spectrum begins to flatten out at the high end; the sooner it begins to flatten out, the less serious is the effect of the splice. In general it turns out that the effect of the splice is small compared with the statistical sampling effect. For the latter, results similar to Tukey's[1] have been derived. For a given sample length, the combination of accuracy and resolution is fixed, i.e., one can increase accuracy only at the expense of resolution and vice versa. Specific results of the calculations will be shown and applied to experimentally measured spectra.

* This work was supported by the U. S. Navy Bureau of Ordnance.
[1] J. W. Tukey, "Sampling theory of power spectrum estimates," Symposium on Applications of Autocorrelation Analysis to Physical Problems, Woods Hole, Massachusetts, June, 1949 (U. S. Office of Naval Research).

SATURDAY MORNING AT 9:45

Horace Mann

(M. GOLDHABER presiding)

Beta and Gamma Emitters, I

R1. Gamma-Ray Spectrum of the Bulk Shielding Reactor. FRED MAIENSCHEIN AND TEMPLE LOVE, *Oak Ridge National Laboratory.*—Spectral measurements have been made of the gamma rays emitted by the Bulk Shielding Reactor (BSR) at the Oak Ridge National Laboratory and of the gamma rays transmitted from the reactor through various thicknesses of

water. The power of the BSR, which consists of an assembly of aluminum-clad enriched uranium fuel elements with water moderator and coolant, was determined from the fission rate which had been previously measured with uranium fission foils. Gamma-ray spectral measurements were made with a multiple-crystal scintillation spectrometer employing both the Compton effect and pair production to give a unique energy response. Energy and sensitivity calibrations of the spectrometer were made using natural radioactive sources whose disintegration rates were determined with an ionization chamber. The general shapes of the spectra obtained indicated a decreasing flux intensity with increasing gamma-ray energy and a sharp drop-off at ~8 Mev. A definite "hardening" of the spectra with increasing water thickness was apparent. Peaks in the spectra due to neutron capture in the hydrogen of water and in the aluminum of the fuel elements were observed.

R2. Age-Diffusion Theory for Beta Ray Problems.* WM. C. ROESCH, *General Electric Company.*—Bethe *et al.*,[1] showed that problems of electron transport can be reduced to solution of the diffusion (or age) equation. Numerical calculation of the ages and of the integrals appearing in the solutions of typical problems has given results in good agreement with experiments for the practical range of monoenergetic electrons, the absorption coefficient of beta rays, the surface dose rate of an emitting material in contact with a backscatterer of any atomic number, the dose rate near a thin source in a large medium, and the response of ion chambers to gamma rays.

* This paper describes in part work done under contract between the General Electric Company and the U. S. Atomic Energy Commission.
[1] Bethe, Rose, and Smith, Proc. Am. Phil. Soc. **78**, 573 (1938).

R3. The Beta Spectra of O^{14}.* J. R. PENNING AND F. H. SCHMIDT, *University of Washington.*—We have studied the beta rays of 76 sec O^{14} with a scintillation spectrometer to determine more accurately the end-point energy, and to search for a possible ground-state transition. O^{14} is known[1] to decay by positron emission primarily to a 2.3-Mev level in N^{14}. The transition is believed to be $J=0\rightarrow J=0$. The activity was produced by the (p,n) reaction on nitrogen in the University of Washington 60-inch cyclotron. The active gases were conducted to a source chamber by means of a continuous flow system. The radiations were examined by NaI(Tl) and anthracene scintillation spectrometers. The spectrometers were calibrated with several other known β spectra. The principal beta component was counted in coincidence with the 2.3-Mev γ ray. Our tentative value for the end-point energy of this component is 1.830 ± 0.030 Mev. In addition, we observed higher energy β particles which exhibited the same half-life as O^{14}. If we assume that these β particles are due to an allowed-shape transition from O^{14} to the ground state of N^{14}, then we obtain a branching ratio of 3 percent. The log *ft* value is 6.7.

* Partially Supported by the U. S. Atomic Energy Commission.
[1] Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).

R4. Sargent Diagram and *ft* Values for Electron Capture Transitions. J. K. MAJOR AND L. C. BIEDENHARN, *Yale University.**—Knowledge of the disintegration constant λ and the energy W of electron capture transitions is useful in calculating branching ratios and transformation probabilities and in identifying nuclear transitions. While λ may be computed from observed half-lives and known decay schemes, W must be deduced indirectly, from closed decay cycles, mass differences from nuclear reaction or mass spectrometer measurements, positron emission between the same initial and final states, or end points of inner *bremsstrahlung* accompanying electron capture. Earlier studies[1] have been extended to lighter nuclei wherever adequate information on the half-life, branching ratios, and transition energy was available, and a Sargent diagram constructed. Known allowed transitions fall considerably below the line proposed by Feather,[1] but the scatter of the points does not permit differentiation of Sargent curves for different degrees of forbiddenness. Comparative half-lives have also been calculated for capture transitions and will be compared to those for beta emitters.[2]

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission and by Air Research and Development Command, U. S. Air Force.
[1] S. G. Thompson, Phys. Rev. **76**, 319–320 (1949); N. Feather, Proc. Roy. Soc. Edinburgh **63**, 242–256 (1952); Physica **13**, 1023–1025 (1952).
[2] A. M. Feingold, Revs. Modern Phys. **23**, 10–20 (1951); E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399–406 (1950).

R5. Recoil Spectrum in the β Decay of Ne^{19}.* W. PARKER ALFORD† AND DONALD R. HAMILTON, *Princeton University.*—A spectrum of recoil nuclei in coincidence with positrons at an angle of $180°\pm30°$ has been measured in the Ne^{19} β decay. The electrons are detected with a scintillation crystal and the recoils by being accelerated into an electron multiplier. Ne^{19} flows through the vacuum system containing the electron multiplier; this is separated from the β crystal by a thin foil. Electrostatic energy discrimination and time of flight discrimination applied to the recoils define the source volume. Preliminary analysis of present data on the recoil spectrum suggests the presence of scalar interaction in the decay. Further measurements of the recoil spectrum under different geometrical conditions and of the corresponding electron spectrum are in progress.

* This work was supported by the Atomic Energy Commission and by The Higgins Scientific Trust Fund.
† Socony-Vacuum Fellow 1952–1953.

R6. Radiative Electron Capture in Fe^{55}, A^{37}, and Ni^{59}. S. E. SINGER, W. S. EMMERICH, AND J. D. KURBATOV, *The Ohio State University.*—The radiative electron capture spectra of Fe^{55}, A^{37}, and Ni^{59} were investigated with a scintillation spectrometer. The detection efficiency of the NaI(Tl) crystal was determined in the energy range from 300 kev to 1300 kev by means of gamma-ray activities of known intensities. The monoenergetic gamma-ray spectra were applied to the continuous energy spectra for correction of the distortion caused by the Compton effect in the crystal. The data were further corrected for the effects of instrument resolution, and were then plotted after the method of J. M. Jauch.[1] Endpoint energies of 227 ± 10 kev, 815 ± 20 kev, and 1065 ± 30 kev were obtained for Fe^{55}, A^{37}, and Ni^{59}, respectively. The experimentally determined spectral shapes were found to be in agreement with the calculated intensity distributions. The spectrum of Ni^{59} appeared to be independent of the type of transition involved. The calculated value of the total radiative capture intensity for Ni^{59} was found to be consistent with the observed intensity of the radiation if a half-life of approximately 7×10^4 years was assumed.

[1] J. M. Jauch, Oak Ridge National Laboratory Report 1102, 1951 (unpublished).

R7. The Disintegrstion of Cobalt-56. M. SAKAI,* J. DICK, AND J. D. KURBATOV, *The Ohio State University*—The energy levels of Co^{56} have been investigated using a magnetic lens spectrometer and a $\gamma-\gamma$ coincidence scintillation spectrometer. Cobalt-56 was obtained by the proton bombardment of ferric oxide enriched in Fe^{56} (99.84 percent). A carrier-free cobalt sample was separated from the target material by ether extraction of ferric chloride followed by precipitation of the remaining traces of iron. The cobalt source essentially contained Co^{56} thus permitting the study of the low-energy portion of its spectrum without interference from other radioactive species of cobalt. The beta spectrum was found to be complex consisting of two groups, the previously reported 1.50-Mev group and a new lower energy component with an end-point energy of about 0.44 Mev. The energies of five of the gamma rays, 0.835 Mev, 1.23 Mev, 1.74 Mev, 2.60 Mev, and 3.25 Mev were confirmed, but the sixth, previously re-

ported as 2.01 Mev was found to be 2.31 Mev. Using this data and that obtained by $\gamma-\gamma$ coincidence studies a decay scheme will be presented.

* On leave of absence from the University of Tokyo.

R8. Upper Limits for the Lifetimes of Ni^{60}.* Z. BAY, V. P. HENRI, AND F. MCLERNON, *George Washington University.*—Recent differential coincidence measurements gave less than 10^{-11} sec for the mean lives of the two excited states of Ni^{60} resulting from the β decay of Co^{60}. In addition, and also as a check, we have measured times of flight of γ's for a distance as short as 1 cm or less in air using them to correct other time measurements. We have also checked the simultaneity in the Compton scattering of γ's lowering thereby the upper limit of such measurements as given by others[1] by more than two orders of magnitude.

* This work supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Hofstadter and J. A. McIntyre Phys. Rev. **78**, 24 (1950).

R9. Disintegrstion of Arsenic-76. B. B. MURRAY AND J. D. KURBATOV, *The Ohio State University.*—Arsenic-76 decays by negatron emission to selenium-76 and by positron emission to germanium-76. The relative abundance of positron disintegration of arsenic-76 with respect to negatron emission has been studied by means of a Wilson cloud chamber. A chemical procedure was developed to obtain a highly purified source of arsenic. It has been established that the decay ratio of positrons to negatrons is approximately 1:1000. The endpoint of the positron spectrum was observed to be about 670 ± 30 kev. The disintegration of other species by positron and negatron emission will be summarized.

R10. The Radiations of 18-min Br^{80}. L. LIDOFSKY, R. GOLD, AND C. S. WU, *Columbia University.**—A reinvestigation of the radiations of 18-min Br^{80} has been made. A renewal of interest in this nuclide was prompted by conflicting reports on its complexity. Further, the level schemes suggested by these reports were in disagreement with the scheme suggested by the existence of a 620-kev gamma ray in Kr^{80}.[1] 18-min Br^{80} was produced by isomer separation from neutron irradiated bromobenzene. A gamma ray of 620 ± 10 kev was found with $N_\gamma/N_{\beta^-}=0.12\pm0.02$. No gamma ray of energy greater than 620 kev was present with an abundance greater than 1 percent. The beta spectrum was remeasured using the solenoid spectrometer with positron-negatron selecting baffles. The negatron spectrum was consistent with an analysis into two groups separated in end point by ~600 kev. The positron spectrum was found to have the simple allowed shape with an endpoint of 862 ± 10 kev and $N_{\beta^+}/N_{\beta^-}=0.04\pm0.005$. A search was also made for the 49-kev gamma ray of 4.4-hour Br^{80*}. Its abundance was found to be less than 0.0025 per disintegration.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] G. S. Goldhaber and M. McKeown, Bull. Am. Phys. Soc. **28**, 5 (1953).

R11. The Disintegration of Mo^{99}.† C. E. MANDEVILLE AND JAGDISH VARMA,* *Bartol Research Foundation.*—The radiations of Mo^{99} and Tc^{99m} have been re-investigated by means of scintillation spectroscopy. Employing single-channel pulse-height analyzers in coincidence, it has been established that a triple cascade of gamma rays, 741 kev→41 kev→140 kev occurs. The 741-kev radiation is also coincident with a gamma ray at 181 kev by an alternate branch of de-excitation which is equally probable. Radiation at 780 kev is present but is noncoincident with other gamma rays. From these data, a disintegration scheme can be constructed. A gamma ray of energy 372 kev was also detected, and although it appeared to have the proper half-period to be associated with Mo^{99}, was found to be not in immediate coincidence with beta rays or other gamma rays, suggesting that it might be related to an impurity.

† Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* Research Fellow, permanent address, Morena (M.B.) India.

R12. Disintegration of In^{117}. C. L. MCGINNIS, *National Bureau of Standards.*—The radiations associated with In^{117} have been studied with a lens spectrometer and scintillation counters. Cadmium was bombarded with 18-Mev deuterons from the Carnegie Institute of Washington Department of Terrestrial Magnetism cyclotron and In^{117} was obtained by chemical separation from the Cd^{117} parent. The isomeric level of In^{117} decays with a half-life of 1.83 hours, and with the following radiations given with their percent transitions-1.77β (39 percent), 1.61β (16 percent), 0.159γ (16 percent), and 0.315γ (45 percent). The internal conversion coefficient for the 0.315 gamma ray is ~1.3 making it $M4$. By means of a Szilard-Chalmers reaction[1] the ground state was separated from the isomeric level and found to have a 40-min half-life. It decays by an 0.76β followed by 0.56- and 0.159-Mev gamma rays. The following coincidences have been measured: $(\beta)(0.16\gamma)$, $(\beta)(0.56\gamma)$, $(0.56\gamma)(0.16\gamma)$. The 0.315γ is not in coincidence with either β or γ rays. The energies were measured with the mixed activity. In^{117} is not the parent of 14-day Sn(<1 percent).

[1] G. J. Goldsmith and E. Bleuler, J. Phys. Colloid Chem. **54**, 717 (1950).

R13. On the Disintegration of I^{130}. R. S. CAIRD AND ALLAN C. G. MITCHELL, *Indiana University.**—The disintegration of I^{130} has been re-examined with the help of a magnetic lens spectrometer and coincidence counting apparatus using scintillation counters. In addition to the lines at 0.409, 0.528, 0.660, and 0.744 Mev reported by Roberts *et al.*[1] a line at 1.15 Mev has been found. Two beta-ray groups[1] are emitted whose energies are 1.02 and 0.597 Mev. Coincidence experiments show that the line at 0.744 Mev is in coincidence with those at 0.409, 0.528, and 0.660 Mev. The line at 1.15 Mev is in coincidence with those of 0.660 and 0.528 Mev but not those at 0.744 and 0.409. These experiments fix the position of the 0.744- and the 0.409-Mev lines. The internal conversion coefficients of the lines at 0.528, 0.660, and 0.744 Mev show that they are $E2$ radiation. The line at 1.15 Mev is $E1$. The energy level scheme will be discussed in the light of the collective model.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] Roberts, Elliott, Downing, Peacock, and Deutsch, Phys. Rev. **64**, 268 (1943).

SATURDAY MORNING AT 9:45

Havemeyer 309

(J. E. GOLDMAN presiding)

Magnetism

RA1. Lattice of Partly Permanent Dipoles. M. LAX AND R. TOUPIN, *Syracuse University.*—In a previous paper,[1] the statistical mechanical analysis of a lattice of permanent dipoles was presented within the approximation we call the spherical model. This approximation, which renders the problem of determining the partition function tractable, replaces

the N constraints, that each dipole be of fixed length, by the single requirement that the combined lengths have the correct value. It was shown that such a model possesses a critical temperature (a discontinuity in the slope of the susceptibility *vs* temperature relation), above which the model behaves as a lattice of induced dipoles with an effective, temperature dependent, polarizability. We have extended the above analysis to include the case of a lattice of permanent dipoles having in addition an induced component. The spherical model approximation is again made in order to treat the permanent component while the induced component is handled exactly. The general features of the results remain unchanged and include the previous result as a special case. We find that, if a simple type of spectrum be assumed for the dipole interaction, the Onsager result[2] is obtained for the behavior of the spherical model above the critical temperature.

[1] M. Lax, J. Chem. Phys. **20**, 1351 (1952).
[2] L. Onsager, J. Am. Chem. Soc. **58**, 1486 (1936).

RA2. Critical Temperature and Susceptibility of Dipole Lattices. R. Toupin and M. Lax, *Syracuse University.*—The determination of the critical temperature and susceptibility of a lattice of dipoles involves the mean eigenvalue $F(t)$ of the operator $(t-\mathbf{G})^{-1}$, where $\mathbf{G}_{ij}=\nabla\nabla 1/r_{ij}$. In particular, if λ_{max} denotes the maximum eigenvalue of $\mathbf{G}$, then $F(\lambda_{max})$ determines the critical temperature. The function $F(t)$ can be expanded as a series in inverse powers of t; the coefficients are the moments of the eigenvalue spectrum of $\mathbf{G}$. The moments up to, and including the third, have been determined exactly by a cluster sum method.[1] The very high moments of the spectrum are determined almost entirely by the behavior of the eigenvalue spectrum in the neighborhood of the maximum eigenvalue. A first approximation to the function $F(t)$ is obtained by using the exact values of the first three moments and the asymptotic form for all higher moments. An estimate is then made of the difference between the exact and approximating functions, by performing a numerical integration of the difference over the eigenvalue spectrum using the symmetry points of the spectrum. The transition temperature T_c for a simple cubic lattice of permanent dipoles in the spherical model approximation is given by $n\mu^2/3kT_c = F(\lambda_{max})=0.74$. The accuracy of the calculation is estimated to be about 3 percent.

[1] R. Rosenberg and M. Lax, J. Chem. Phys. **21**, 424 (1953).

RA3. The Magnetic Susceptibility of the Transition Elements. C. J. Kriessman, *Remington Rand,* and H. B. Callen,* *University of Pennsylvania.*—A theoretical treatment of the temperature dependence of the paramagnetic susceptibility of the transition elements according to the band theory of solids, is developed explicitly by means of a simple approximation to the Fermi function. The resulting formulation may be graphically interpreted in terms of the density-of-states curve, and the temperature dependence is divided into two distinct mechanisms: (1) the variation with temperature of the width of the Fermi distribution, and (2) the variation with temperature of the Fermi energy. On the basis of the approximate theoretical density-of-states curves which have been computed for the transition elements, the competition of these two mechanisms is found to lead to susceptibilities which are qualitatively in agreement with experiment. In particular, the observed alternation in sign of susceptibility from column to column of the periodic table, and the various maxima and minima in the temperature dependence of the susceptibility, follow from the simple graphical constructions of the theory.

* Supported in part by the U. S. Office of Naval Research.

RA4. High Field Non-Brillouin Moments for Cobalt Sulfate Heptahydrate. Warren E. Henry, *Naval Research Laboratory.*—A high-field induced paramagnetic anomaly in nickel fluosilicate hexahydrate has been previously reported.[1] Branching of the magnetic isotherms occurred at high fields when the moment was plotted against H/T. In this case, the dispersion of the isotherms increased as H/T was increased. However, the saturation range was not easily availabe for the nickel fluosilicate and it was decided to study cobalt sulfate heptahydrate, which from measurements on the low-field susceptibilities by Fritz and Giauque[2] should tend to saturation more easily. The magnetic isotherms show the same type of high-field accentuated branching but yield considerable data in the range near saturation, i.e. where $(\partial M/\partial H)_T$ is small. Analysis of the experiments shows a nonlinear dependence of energy levels on magnetic field.

[1] W. E. Henry, Bull. Am. Phys. Soc. **28**, 6, 31 (1953).
[2] J. J. Fritz and W. F. Giauque, J. Am. Chem. Soc. **71**, 2168 (1949).

RA5. Antiferromagnetism in Cupric Oxide.* B. N. Brockhouse,† *Brookhaven National Laboratory.*—Neutron powder diffraction studies of CuO at low temperatures show the existence of a weak line corresponding to the $\bar{1}01$ line of a unit cell of double the normal size. This line was not observed with x-rays and has a temperature dependence of the kind shown by lines of magnetic origin, disappearing at about 230°K. This apparent Néel temperature coincides within the uncertainties to the temperature (220°K) of a specific heat anomaly. In the monoclinic structure, the copper atoms occupy $\bar{2}02$ planes of the normal cell in equal numbers. The appearance of the $\bar{1}01$ line of the doubled cell means that alternate planes of copper atoms are coupled antiferromagnetically. This fits in well with current ideas about antiferromagnetism in oxides; for each copper atom is coupled to a copper atom one plane away through a copper-oxygen-copper link in which the angle is about 145 degrees. Other Cu-O-Cu angles in the structure are smaller. The intensity of the line sets a lower limit of $0.5\mu_B$ for the magnetic moment per copper atom.

* Work partly performed at BNL under auspices of U. S. Atomic Energy Commission and partly at Chalk River Laboratories, Atomic Energy of Canada, Ltd.
† Guest of BNL Reactor Department, on leave from Atomic Energy of Canada, Ltd.

RA6. Volume Magnetostriction in Nickel and its Alloys.* K. Azumi and J. E. Goldman, *Carnegie Institute of Technology.*—The volume magnetostriction is related to the pressure dependence of the magnetic moment through the thermodynamic identity $(\partial V/\partial H)_p=-(\partial M/\partial p)_H$ and its sign is, therefore, sensitive to the position of the element on the Bethe-Slater curve relating the exchange interaction to atomic separation. It is generally assumed that nickel lies on the decreasing portion of this curve. Recent experiments on the pressure dependence of the magnetization confirm this. On the other hand, the sign of volume magnetostriction as measured by Kornetzki and by Snoek do not support this view. We have adapted the resistance-strain gauge technique to the measurement of the volume magnetostriction and have obtained results on nickel and two nickel-copper alloys. The sample is in the form of a rectangular paralelopiped; and strain gauges, mounted in each of the three orthogonal directions, are connected in series. Good thermal contact is made with the magnet and great care is exercised to permit the sample to return to thermal equilibrium. We find the volume magnetostriction in all three cases to be negative, confirming the pressure effects but in disagreement with the previous investigations. A possible source of the discrepancy may be the difficulty of returning to thermal equilibrium in a liquid dilatometer after magnetization.

* Supported by U. S. Office of Naval Research.

RA7. A Method for Measuring Magnetization and Susceptibility at Low Temperatures.* A. Arrott,† *Carnegie Institute of Technology* (introduced by J. E. Goldman).—An apparatus is described for the measurement of magnetization at liquid

helium temperatures. A cylindrical sample is placed in a uniform field. A current is passed through a coil wound around the cylindrical surface of the sample and adjusted to restore the uniform B field. The current then measures the magnetization. The null is detected by moving the sample from within one detector coil to another connected in series opposition. The sensitivity of the apparatus permits measurements of volume susceptibility as small as $\sim 10^{-6}$ to a reasonable degree of accuracy. The heating of the null coil limits the range of applicability of the method to values of magnetization smaller than the order 10 emu. In addition to the obvious advantage of measuring in a uniform field, it is pointed out that the magnetization will be uniform inside a cylindrical sample because of the presence of the null coil. The restoration of the uniform B field eliminates image effects.

* Supported by U. S. Office of Naval Research.
† Allis-Chalmers Research Fellow.

RA8. Magnetic Susceptibility of Nickel-Copper and Nickel-Chromium Alloys.* J. E. GOLDMAN AND A. ARROTT, *Carnegie Institute of Technology.*—Extrapolation of the magnetic properties of nickel-copper and nickel-chromium alloys measured at high nickel concentrations, suggests that the spontaneous magnetization at 0°K should disappear at 60 percent copper and ~14 percent chromium, respectively. The nature of the magnetism in the alloys with higher concentration of the nonferromagnetic constituent is not clearly understood. We have made measurements of the magnetization down to 2°K on samples of alloys in this range of composition. We find the alloys containing 58 and 63 atomic percent copper in nickel to be ferromagnetic. The temperature dependence of this ferromagnetism has been studied. In the case of nickel-chromium alloys, the behavior is paramagnetic and the possibility of a ferrimagnetism or antiferromagnetism seems to be precluded. The results will be discussed on the basis of the collective electron treatment, the parasitic paramagnetism of Néel, and the role of possible concentration fluctuations within the material.

* Supported by U. S. Office of Naval Research and a grant from the Allis-Chalmers Manufacturing Company.

RA9. Hall Effect in Ferromagnetics. J. M. LUTTINGER, *University of Michigan.*—It is well known that the Hall effect in ferromagnetics shows a very anomalous behavior. This may be summarized by saying that an "effective field" $H_{eff}=H_0+4\pi M\alpha$ acts (H_0 external field, M magnetization), where α instead of being of the order of unity, varies from this value at very low temperatures to as much as several hundred at higher temperatures. A theory is proposed which gives a qualitative account of the magnitude and temperature dependence of α. This theory is based on the fact that electrons with their spins oriented will have, because of spin-orbit interaction, an extra right-left asymmetry in their wave functions. This asymmetry gives rise to a current perpendicular to an applied electric field, to the spin, and proportional to the degree of polarization of the electrons or to the magnetization of the sample. The predicted temperature dependence, based on rough estimates of the quantities involved, is as the resistivity (ρ) squared of the material. This is qualitatively what is observed in Fe and Ni, though the situation seems not quite so simple in ferromagnetic alloys. Using the known spin-orbit coupling, one can estimate the coefficient of ρ^2, and this, too, can be fitted to experiment without implausible assumptions about the electronic wave functions of ferromagnetics.

SATURDAY MORNING AT 9:45

Pupin 428

(F. N. FRENKIEL presiding)

Fluid Dynamics

Business Meeting of the Division of Fluid Dynamics

S1. Structure of the Vibration Pattern of Transverse Waves in Slow Circular Jets. R. L. WEGEL* AND H. C. RORDEN, *Bell Telephone Laboratories.*—A series of measurements were made on two circular air jets of the mean steady impact pressure distribution and of the accompanying fluctuating pressure caused by a simple single frequency sound source placed beside it at the nozzle. The test frequency was varied from 100 to 20 000 cycles per second. The steady pressure decreased with distance, at first slowly and then rapidly, spreading radially according to a law resembling diffusion. A transverse wave is transmitted along the jet with amplitude increasing to a distance of about six nozzle diameters and then decreasing. The phase velocity decreases slightly with distance and increases slowly with frequency, being always somewhat less than the local jet speed. The amplitude decreases with radial distance to a minimum just outside the nominal jet radius and then passes over a second maximum. The phase lags increasingly with radius to the minimum amplitude point where it reverses suddenly.

* Retired.

S2. On the Stability of Vortex Sheet in Inviscid Compressible Fluid. SHIH I. PAI, *University of Maryland.*—The stability of vortex sheet in inviscid compressible fluid with respect to two-dimensional small disturbance is investigated. A new simple criterion for complete stability of this case is found. The significance of "supersonic," "sonic," and "subsonic" disturbances is discussed. It is found that only the supersonic neutral stable disturbance with respect to the free stream gives continuous eigenvalues. The determinantal equation for "supersonic" damped or self-excited disturbance with respect to the free stream here may be reduced to the same simple form as those for other subsonic or sonic disturbance, and the eigenvalues so obtained are discrete.

S3. Diffraction of Step Shocks Through Double Slits. GEORGE A. COULTER AND JAMES ALLEN, *Aberdeen Proving Ground.*—An experiment, using a four and one-half inch shock tube, is described, showing the results obtained when a step shock wave is allowed to be diffracted by a wall with two one-eighth by one-eighth inch slits spaced one inch apart. The effects of the wall were made two dimensional by letting the length of the slits extend across the vertical diameter of the tube. Spark shadowgraphs of the resulting phenomena, after the shock wave has been diffracted through the slits, are shown. Measurements taken from shadowgraphs are presented

in graphical form for five different peak pressures incident upon the wall. These pressure values are the calculated shock pressures before diffraction. These graphs include a space-time plot of the motion of the cylindrical diffracted front as it progresses outwardly from the slit; a space plot of the "triple point" of the Mach interaction region between the diffracted wave fronts after "reflection" has occurred; and a space plot of the extreme points of the various vortices as they move away from the slits.

S4. A New Approach to the Theory of Turbulence in Gases. M. Z. VAN KRZYWOBLOCKI, *University of Illinois* (introduced by G. Plain).—The author discusses briefly the existing theories of turbulence like mixing-length theory, isotropic homogeneous, locally isotropic, etc. He points out that the existing theories of turbulence assume as the principle the turbulent fluctuations of the macroscopic properties of a gas. When we refer to the statistical mechanics, it is clear that its purpose is to derive all the macroscopic properties of matter from the microscopic properties of molecules; the term includes, according to recent practice, nonequilibrium as well as equilibrium states. Staring from this point of view the author presents a new approach to the theory of turbulence based upon the concept of the turbulent fluctuations of some microscopic properties of the gas molecules.

S5. An Unnecessary, Restrictive Concept in Turbulent Boundary Layer Theory.* DONALD ROSS, *The Pennsylvania State College.*†—The concept of the overlap of the inner and outer velocity functions of a turbulent boundary layer is often assumed in theoretical analyses. Although this concept is thought to be proved by the confirmation of the logarithmic velocity and friction laws, actually it is only a sufficient condition and not a necessary one. In analyses of nonequilibrium flows, it is a restrictive condition that has in the past led to erroneous conclusions. Even for the equilibrium profiles for which it was originally postulated, overlap is an unnecessary restriction. When it is eliminated, the von Kármán similarity theory is found to be in better agreement with measured flat-plate, boundary-layer profiles. Similar conclusions for pipe flow lend support to the contention that this is an unnecessary, restrictive concept that should be discarded.

* Work partially supported by the U. S. Office of Naval Research.
† Now at the Bell Telephone Laboratories.

S6. Isotropic Temperature Fluctuations in Isotropic Turbulence.* ALAN KISTLER, VIVIAN O'BRIEN, AND STANLEY CORRSIN, *The Johns Hopkins University.*—Preliminary measurements have been made with hot-wire anemometer in the flow behind a "hot grid." Temperature auto-correlation shows a reasonable degree of isotropy, and the relative decay rates agree fairly well with the isotropic relative decay equation, showing that the field and the measurement technique are suitable for more detailed studies.

* Work supported by the National Advisory Committee for Aeronautics.

S7. A Measure of the Area of a Homogeneous Random Surface in Space.* STANLEY CORRSIN, *The Johns Hopkins University.*—We are given an indefinitely large space containing random surface or surfaces homogeneously located in the mean. The problem is to relate the average area of surface per unit volume of space to a simpler statistical quantity, in particular the average number of cuts per unit length made by a straight randomly directed sampling line with the surface. The plane case is studied first. After the three-dimensional case, application is made to extending to two- and three-dimensional variables a theorem of S. O. Rice on the average occurence rate of any particular value of a one-dimensional random variable.

* Supported by the U. S. Office of Naval Research.

S8. The Design of Diffusers to Avoid Turbulent Boundary Layer Separation. FRANCIS H. CLAUSER, *The Johns Hopkins University.*—A recent experimental investigation* obtained information about the behavior of turbulent boundary layers in adverse pressure gradients which were so adjusted that the layers had similar velocity profiles throughout their length. The appropriate nondimensional pressure gradient parameters were also constant throughout the length of the layers. It was found, contrary to general belief, that the layers able to withstand the highest pressure gradients were not those having velocity profiles nearest those of separation profiles, but rather intermediate profiles having shapes not too far removed from constant pressure profiles. The information obtained is sufficient to permit the design of diffusers having shapes for maximum diffusion. Such diffusers can give unlimited amounts of diffusion without separation. The diffuser shapes are particularly easy to calculate if the free-stream velocity is considered to be constant across the channel. The resulting shapes are not straight sided, but expand most rapidly at first where the boundary layers are thin and less rapidly as the boundary layers grow. The expansion rates are greatly affected by the thickness of the boundary layer at the beginning of the expansion, a fact not usually taken into account in the design of diffusers for wind tunnels and the like. This work was supported by the U.S.A.F. under contract AF 33 (038)9862.

* Francis H. Clauser, "Turbulent boundary layers in adverse pressure gradients," Francis H. Clauser, J. Aeronaut. Sci. (to be published).

S9. On Triple Correlations in Isotropic Turbulence.* R. BETCHOV, *University of Maryland.*—In a turbulent flow, the three points-three velocities correlation functions form a tensor depending on the two displacement vectors A and B. This tensor can be developed in a double power series in A and B with coefficients defined at one point only. Assuming incompressibility and isotropy relative to rotations and reflexions about one point, we found that the coefficients of the cubic terms in A^3, AB^2, etc., are all proportional to the mean cube of the local acceleration, that is to the skewness coefficient. Investigations on the stability of such a turbulent flow for perturbations of moderately high-wave numbers lead to the eigenvalues of certain kinematic determinants. The mean values of these determinants are proportional to the skewness coefficient and this parameter appears therefore as an essential quantity. Experimental measurements in a turbulent flow behind a grid agree with various consequences of isotropy and confirm the relation between the skewness and the Reynolds number of the turbulence. Furthermore, we found that the mechanism responsible for the skewness coefficient is highly intermittent.

* This work is supported by the Office of Air Research and Development Command.

S10. The Hugoniot of Gases by Shock Wave Measurements. RUSSELL H. CHRISTIAN AND ROBERT G. SHREFFLER, *Los Alamos Scientific Laboratory.*—Equation of state data are derivable from the simultaneous measurement of the velocity of a plane shock front through a gas and the velocity of the plate that generates the shock. The present experimental method employs a high explosive lens system to accelerate the plate into the gas. Velocities are recorded by a high-speed moving image camera with precisions of the order of 0.5 percent. A series of such experiments determines the experimental shock velocity *vs* particle velocity curve for a given gas. Experimental data have been obtained for air, argon, helium, and nitrogen. The method permits measurements using shocks in the pressure region of approximately 200 to 1000 atmospheres. The lower limit is defined by the failure of the gas to become luminescent on reflection. The upper limit is determined by the maximum particle velocity attainable with high explosives. The Rankine-Hugoniot shock equations are

used to convert the experimental data to pressure-compression data which define the Hugoniot curve. A comparison is made to theoretical predictions.

S11. Statistical Uncertainties in the Radiographic Determination of Gas Densities. DOUGLAS VENABLE AND LEO F. PERRY, *Los Alamos Scientific Laboratory.*—The uncertainties in the measurement of gas densities by flash radiographic techniques arise from the statistical fluctuation of the quanta absorbed in the specimen, the inherent instrumental errors, and inadequate time resolution. For small numbers of useful quanta the statistics of absorption can constitute the predominating error term. The absorption statistical uncertainty in measuring densities in nitrogen and argon have been worked out for the continuous x-ray spectrum of tungsten as a function of peak energy and path length for the charge delivered to the x-ray source and for the useful solid angle subtended by the detector at the target. For purposes of this work the intensity distributions, determined experimentally by Ulrey[1] and Kuhlenkampff,[2] were employed. An experimental setup was made using a 25-kev thin-window, tungsten target x-ray tube with an appropriate absorption cell and scintillation detector. Absorption in the tube window and cell windows was unimportant for the path lengths covered, 10^{-2} to 2×10^{-1} g/cm^2 of nitrogen. The experimentally determined fractional error in density appears in good agreement with prediction when using a quantum efficiency coefficient of 1.1×10^{-9} per volt.

[1] Ulrey, Phys. Rev. **11**, 401 (1918).
[2] Kuhlenkampff, Ann. Physik. **69**, 548 (1922).

S12. Observations of Taylor Instability in Gases. R. E. DUFF AND H. T. KNIGHT, *Los Alamos Scientific Laboratory.*—Taylor instability has been observed in the gaseous system of SF_6 and air by means of a schlieren optical system and an Eastman high-speed movie camera. The gases were subjected to gravitational acceleration only. An interface between the two gases was produced by withdrawing a thin steel slide that separated them in a cell 8 in. high×4 in. wide×1 in. deep. A pulling velocity 30 ft/sec could be used without introducing observable turbulence in the interface. The results obtained for initial rate of growth of instability as a function of wave number were in agreement with theory.[1] The spikes of heavy gas had rounded ends and moved slower in the late stages of development than predicted by theory.[2] Their amplitude grew approximately as $t^{1.4}$ instead of t^2. Under these conditions the instability region appears symmetrical about the original interface.

[1] Pennington, Princeton University Report, "Effects of surface tension and viscosity on Taylor instability" (1952).
[2] Carrier (private communication, 1953).

S13. Precision Measurement of Detonation and Strong Shock Velocity in Gases. HERBERT T. KNIGHT AND RUSSELL E. DUFF, *Los Alamos Scientific Laboratory.*—A system is described for determining detonation and strong shock velocity in gases by using the conductivity behind the wave.[1] Wave contact is made by two 36-mil wires set 0.1 inch apart in a Teflon plug mounted in the experimental tube. When a wave passes, signals are produced across a 30K resistor in series with these wires and a 0.001 μf. capacitor charged to 300 volts. Any number of circuits may be parallel across a single signal resistor if a diode is added to each circuit to prevent signal deterioration. The arrival time of a wave at a pin can be determined with an accuracy of almost 10^{-8} second from an oscilloscope record of the signals. A check of the system was made by measuring the velocity of five presumably identical detonations in a 40–60 acetylene-oxygen mixture. The total spread in velocity was 4.0 m/sec and the standard deviation was 1.3 m/sec. The principal advantages of this system are excellent space resolution and very simple basic circuitry.

[1] A crude application of this principle was reported after the beginning of this development by Resler, Lin, and Kantrowitz, J. Appl. Phys. **23**, 1390 (1952).

S14. Shock Tube Experiments on Grid Flow. LESLIE S. G. KOVÁSZNAY AND DARSHAN DOSANJH, *The Johns Hopkins University.*—A traveling plane shock wave is partly reflected and partly transmitted when arriving at a grid. Associated flow phenomena have been studied in a shock tube both by optical techniques and by the hot-wire anemometer. The pressure drop coefficient of the grid has been inferred by measuring the speeds of both transmitted and reflected shock waves. The turbulent flow emerging from the grid offers a good possibility of studying shock-wave interactions with homogeneous turbulent flow.

SATURDAY MORNING AT 9:45

Schermerhorn 501

(GREGORY BREIT presiding)

Nucleonic Scattering

Contributed Papers

T1. Attenuation of 870-Mev Protons by Various Elements.* F. F. CHEN, C. P. LEAVITT, AND A. M. SHAPIRO, *Brookhaven National Laboratory.*—The total interaction cross sections of Be, C, Al, Cu, Sn, and Pb for 870-Mev protons have been measured using an external proton beam scattered from a target in a cosmotron straight section. The incident beam was collimated, magnetically analyzed, and then defined by three 2½-in. diameter scintillation counters in fast coincidence. The meson contamination was less than 1 percent. A 6-in. diameter counter measured the transmitted beam. Preliminary results for the attenuation cross section in a geometry of 8° subtended half-angle are, in barns: Be, 0.21; C, 0.25; Al, 0.45; Cu, 0.85; Sn, 1.3; Pb, 2.1. The statistical uncertainty was in most cases less than 5 percent. These cross sections are close to $\sigma_{\text{absorption}}$ in the sense of the optical model, with small corrections to be made for (a) the diffraction scattering tail, (b) multiple and single Coulomb scattering, and (c) charged products of interactions emitted in the forward direction. In order to determine these corrections, it was necessary to repeat the measurements in several geometries and with several absorber thicknesses. The same procedure in "good" geometries may permit a determination of the diffraction cross section. Comparison with the optical model will be discussed.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.

T2. Elastic Scattering of 340-Mev Protons by Deuterons.* † DAVID D. CLARK‡§ AND OWEN CHAMBERLAIN, *University of California, Berkeley.*—The differential cross section has been measured at eight angles employing a coincidence system detecting both emergent particles. Elastic events were separated from inelastic events in which two fast protons emerged by identification of the deuterons by pulse heights from a counter telescope. Observed center-of-mass cross sections were: 30° (center-of-mass), 2.2 mb/sterad; 40°, 1.0; 50°, 0.39; 70°, 0.11; 90°, 0.047; 110°, 0.042; 130°, 0.044; 150°, 0.10. The total (statistical and systematic) errors varied from 15 to 20 percent. Comparisons with theory using impulse approximation methods of Chew[1] and Chamberlain and Stern[2] show fair agreement between theory and experiment and indicate that effects of interference between scatterings from the two centers of the deuteron are small.

* Work done under auspices of the U. S. Atomic Energy Commission.
† Based on Ph.D. thesis of one of us (D.D.C.) submitted to the Graduate Division, University of California, Berkeley.
‡ For a portion of the period of this research, U. S. Atomic Energy Commission Pre-Doctoral Fellow.
§ Now at Brookhaven National Laboratory.
[1] G. F. Chew, Phys. Rev. **84**, 1057 (1951).
[2] Chamberlain and Stern, (to be published).

T3. Proton-Alpha Scattering at 17.5 Mev.* KARL W. BROCKMAN, JR., *Princeton University.*—The differential cross section for the scattering of 17.5-Mev protons by helium has been measured. Particles were detected using a potassium iodide scintillation counter. The experiment was performed in Princeton's 60-inch precision scattering chamber. This apparatus permitted measurements at center-of-mass angles ranging from 6.4 to 168 degrees. Thirty-three angles in all were used. Counting statistics of 1.5 percent or better were obtained throughout. Other errors are estimated to be no greater than 0.5 percent except at the smallest angles where it was necessary to apply corrections amounting to several percent in the reduction of the data to the cross section. Work on the analysis of the data is in progress.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.

T4. The Elastic Scattering of 18.5-Mev Protons by Nuclei.* I. E. DAYTON AND P. C. GUGELOT, *Princeton University.*—The absolute differential cross section for the elastic scattering of 18.5-Mev protons has been measured for aluminum at 35 angles between 15 degrees and 172 degrees. The statistical error at each point is less than 3 percent. The protons are detected by a sodium iodide crystal with about 2.3 percent energy resolution. Protons to the lowest level in Al^{27}, which is at 0.845 Mev, are clearly resolved from the elastic group. The angular width of the counter is about one-third of a degree. The cross section shows a very sharp minimum at 44 degrees, with maxima at 62 degrees, 123 degrees, and apparently at 180 degrees. Calculations using the optical model[1,2] with a potential $V=(-45-21i)$ Mev follow the general trend of the data, but they completely fail to reproduce its detailed structure. Measurements on other elements are in progress and will be reported at the meeting.

* Supported by the Higgins Scientific Trust Fund and the U. S. Atomic Energy Commission.
[1] R. E. LeLevier and D. S. Saxon, Phys. Rev. **87**, 40 (1952).
[2] D. M. Chase and F. Rohrlich, Phys. Rev. (to be published).

T5. Scattering of 96-Mev Protons from Light Nuclei.* I. Energy Distribution. F. TITUS AND K. STRAUCH, *Harvard University.*—The 96-Mev external proton beam of the Harvard cyclotron is being used to investigate the elastic and inelastic scattering from light elements. Proton energy spectra have been observed at 40° with Li, Be, B, C, NaN_3, H_2O, NaF, and Na targets, using a range telescope. The over-all energy resolution of the system including the beam is about 3 Mev. The characteristic features of the proton spectra are: (1) an elastic peak; (2) inelastic peaks decreasing in height with decreasing energy; (3) an unresolved continuum increasing in height with decreasing energy. Although in some cases no corresponding level has been reported, in general the positions of the inelastic peaks correspond to known excited levels of the target nuclei. For example, peaks are observed from C at 4.3, 10.0, and 20.9 Mev (±1 Mev) below the elastic peak. With Li, a very sharp peak is seen at 4.8 Mev and less prominent peaks seem to exist at 15.8 Mev and 20.7 Mev below the elastic peak. With Al, only the elastic peak has been resolved.

* Assisted by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

T6. Scattering of 96-Mev Protons from Light Nuclei.* II. Angular Distribution. K. STRAUCH AND F. TITUS, *Harvard University.*—Energy spectra of protons scattered from C and Al targets have been measured at several angles from 22.5° to 70° with an angular resolution of 3.5° or less. The scattering cross section decreases rapidly with angle and in general, the higher the energy of the scattered protons the more rapid the decrease. For Al the elastic peak height decreases in amplitude by a factor of 200 from 22.5° to 60°. A diffraction minimum appears at about 30°. At the larger angles, separation between elastic and inelastic protons becomes difficult. For C the elastic and first inelastic peak height decrease by factors of 77 and 49, respectively, from 30° to 70°, with smaller decreases for the lower-energy peaks. The complete results suggest that the inelastic peaks are produced by single nucleon-nucleon collisions in the target nucleus.

* Assisted by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

T7. Elastic Scattering of 14-Mev Neutrons.* J. H. COON AND R. W. DAVIS, *Los Alamos Scientific Laboratory.*—Measurements of angular distributions for elastic scattering of 14-Mev neutrons were made in the angular range from 6° to 50°. A ring scattering geometry similar to that employed by Amaldi *et al.*[1] was used. The neutrons were detected by means of a small stilbene scintillation counter, pulses from which were fed into a multi-channel pulse-height analyzer. Elements investigated were C, Al, Cu, and Sn. Strong forward scattering was observed, the angular width of the forward peak decreasing with increase in nuclear radius. Integration of the observed differential cross-section curves indicate that for the above listed elements probably not more than 20 percent of the elastic scattering is through angles greater than 50°.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Amaldi, Bocciarelli, Cacciapuoti, and Trabacchi, Nuovo cimento **3**, 203 (1946).

T8. Interpretation of Measurements of the Total Cross Sections for Nuclear Scattering of High-Energy Neutrons. T. B. TAYLOR, *Cornell University and Los Alamos Scientific Laboratory.*—It has been possible to get observed total neutron cross sections for various elements[1,2] for neutron energies between 60 and 400 Mev by using the nuclear model and method of calculation described by Fernbach, Serber, and Taylor.[3] The nuclear radii, the average nuclear potential V, and the mean free path for inelastic scattering of neutrons in nuclear matter K are obtained by making a "best fit" to the experimental data. V and K are allowed to depend upon the neutron energy. The nuclear radii turn out to be a nonlinear function of $A^{\frac{1}{3}}$, and are equal to $1.55A^{\frac{1}{3}}$ for light elements (Carbon) and $1.35A^{\frac{1}{3}}$ for heavy elements (Lead). The nuclear radii obtained from this analysis will be compared with those obtained by other methods. Possible connections between K and V and the free nucleon-nucleon interactions will be discussed.

[1] A. E. Taylor and E. Wood, Phil. Mag. **44**, 95 (1953).
[2] V. Alexander Nedzel, Phys. Rev. **91**, 440 (1953).
[3] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

T9. Angular Distribution of Neutrons Scattered from Cadmium, Tin, and Bismuth.* S. C. SNOWDON AND W. D. WHITEHEAD,† *Bartol Research Foundation.*—The differential cross sections for the scattering of 3.7-Mev neutrons from cadmium, tin, and bismuth have been measured over an angular range between 13 degrees and 140 degrees with an angular resolution of about ±10 degrees. The effects due to higher-order scattering have been removed at each measured angle by extrapolation of the observed differential cross section to zero thickness scatterer. A possible explanation of the results in light of the continuum theory of nuclear reactions will be given.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Present address, North Carolina State College, Raleigh, North Carolina.

T10. Angular Distributions of 0.2–1.5 Mev Neutrons Elastically Scattered by Light Nuclei. H. B. WILLARD, J. K. BAIR, AND J. D. KINGTON, *Oak Ridge National Laboratory.*—Neutrons produced in the forward direction by the $Li^7(p,n)Be^7$ reaction were scattered elastically by cylindrical samples of lithium, beryllium, boron, and carbon. Samples were chosen to give a transmission of greater than 70 percent in order to keep multiple scattering to a minimum. Angular distributions were measured with a proton recoil counter shielded from the primary beam by a paraffin wedge. The bias was set to approximate a flat response from the incident neutron energy down to 0.6 this value, so that no correction was necessary for the variation of the scattered neutron energy with laboratory angle. Backgrounds were of the order of 50 percent. The resonances at 0.26 Mev in Li^7, 0.62 Mev in Be^9, and 1.28 Mev in B^{11} are of the form $B_0+B_2P_2(\cos\theta)$ in the center-of-mass system, whereas the resonance at 0.43 Mev in B^{11} is nonsymmetrical about 90° indicating interference. Nonresonant scattering at 0.5 Mev in Li^7, Be^9, B^{10}, and C^{12} is nearly isotropic. At 1.5 Mev B^{10} has strong forward scattering, while C^{12} remains nearly isotropic. Spin and parity assignments to the levels studied have been tentatively made.

T11. Attenuation of 14.1-Mev Neutrons in Water.* R. S. CASWELL, R. F. GABBARD, W. P. DOERING, AND D. W. PADGETT, *National Bureau of Standards.*—The attenuation of 14.1-Mev neutrons in water has been studied under conditions simulating an isotropic point source of monoenergetic neutrons in an infinite water medium. The neutrons were produced by the $H^3(d,n)He^4$ reaction, the deuteron beam from the accelerator striking a tritium-zirconium target located in a large water tank. Thermal neutron flux was measured as a function of distance from the target over the range 5 cm–125 cm with indium foils and a B^{10}-lined counter using the cadmium difference method. The mean square distance for slowing down of 14.1-Mev neutrons to the thermal energies was found to be 980 cm^2. Although the attenuation is not (and should not be) strictly exponential at large distances, over the range 40–125 cm the curve may be approximated by an exponential of attenuation length 14.5 cm. Resonance neutron flux (1.44 ev) was measured with indium foils covered with cadmium. Fast neutron dose measurements were made using a polyethylene-ethylene proportional counter[1] calibrated at 2.5 Mev and 14 Mev with measured fluxes of monoenergetic neutrons. Experimental results are in reasonable agreement with theoretical calculations.[2]

* This research was supported by the U. S. Atomic Energy Commission.
[1] G. S. Hurst and R. H. Ritchie, Radiology **60**, 864 (1953).
[2] H. Goldstein, (private communication).

Invited Paper

T12. Neutron-Proton Scattering Cross Sections at High Energies. W. M. POWELL, *University of California, Berkeley.* (30 min.)

SATURDAY MORNING AT 9:45

Casa Italiana, 1161 Amsterdam Avenue

(M. L. GOLDBERGER presiding)

Theoretical Physics, III

U1. Possible Angular Correlations Involving *V* Particles.* L. WOLFENSTEIN, *Carnegie Institute of Technology.*—It has been suggested by several authors that V_1 particles may have spin greater than $\frac{1}{2}$. It has also been suggested that the spin might be detected from observations on angular correlations of the decay products. In the rest system of the V_1 the decay is necessarily isotropic if the spin is $\frac{1}{2}$. Calculations have been made of the angular correlation between the direction of the decay products in the rest system of the V and the direction of the incident meson for the reaction $\pi^-+p\rightarrow V_1^0+X$ near the threshold where the V_1^0 and X may be assumed to emerge in an s state. If particle X has zero spin, the correlation is completely determined by the spin of the V_1 and is independent of the parity of either X or the V_1. For all spins greater than $\frac{1}{2}$, the direction of the decay products tends to be parallel to the incident meson direction; the correlation, for example, is $(3\cos^2\theta+1)$ for spin $\frac{3}{2}$. Other cases will be discussed.

* Aided in part by U. S. Office of Ordinance Research.

U2. On Relativistic Wave Equations.* HERMAN FESHBACH, *M.I.T.*—The Bhabha form of these equations are considered:

$$(\beta_\mu\partial_\mu+\kappa)\psi=0.$$

A method for generating possible forms for β_μ is developed which requires only knowledge of the sixteen Dirac operators γ_A. A simple procedure for reducing the resultant equations to a reducible form exists, the final equations being expressed in terms of vectors, scalars for the spin 1 equation, spinors, "spinor vectors," and "spinor tensors" for the spin $\frac{3}{2}$ equation, etc. The spin 1 and $\frac{3}{2}$ case have been studied, and the appropriate forms for β_μ, which lead to the Rarita Schwinger form of the $\frac{3}{2}$ spin equation and to a multiple mass equation similar to that developed by Bhabha, have been determined.

* This work was supported in part by the joint program of the U. S. Office on Naval Research and the U. S. Atomic Energy Commission.

U3. Two Extensions of the Foldy-Wouthuysen Transformation. K. M. CASE, *University of Michigan.*—A transformation of spin 0 and 1 wave equations, similar to that given by Foldy

and Wouthuysen[1] for spin ½ has been obtained. For the field-free equations, all the simplifications of interpretation found by these authors persist. Indeed, the Hamiltonian, velocity, and angular momentum operators all have precisely the same form for the three theories with the implicit inclusion of a unit $2S+1$ dimensional matrix. It is indicated that all wave equations of the Dirac-Pauli-Fierz form can be transformed in just this way. The nonrelativistic approximation in the presence of external fields is also readily obtained. A simple explanation of the vanishing of terms proportional to $1/m^2$ in the spin one nonrelativistic Hamiltonian can be given. It was also found that for spin ½ the F–W transformation can be carried out explicitly for an arbitrary time independent magnetic field. The transformed Hamiltonian is shown to be particularly suitable for discussing various properties of a Dirac particle in such a field.

[1] L. L. Foldy and S. A. Wouthuysen, Phys. Rev. **78**, 29 (1950).

U4. A New Approach to the Classical and Quantum Theory of Many Interacting Particles. I. GEORGE J. YEVICK,* *Stevens Institute of Technology*, AND JEROME K. PERCUS, *Columbia University*.—The fundamental idea is the following: We propose to solve the dynamical problem of many interacting particles by replacing the original system by an equivalent formulation. The motion of a collection of $3n$ bounded, one-dimensional harmonic oscillators q_k (k is an index referring to the wave number of the oscillation), whose fictitious masses f_k and frequencies ω_k are at our disposal, has an intimate bearing upon the dynamical behavior of n bodies. This intimate connection is afforded by the collective coordinates $\Sigma_i \exp(i\mathbf{k}\cdot\mathbf{x}_i)$ first extensively developed by Bohm and Pines for long-range forces. Their method is intrinsically incapable of describing short-range forces. Our q_k are simply the collective coordinates. If one substitutes the q_k into the Lagrangian for a set of fictitious oscillators, one immediately obtains an expression containing a term which is the kinetic energy of the real particles, another term which may be interpreted as the potential energy and finally an additional unwanted term which can be considered as a velocity dependent potential. It is this last term which must be minimized by an appropriate choice of the fictitious masses and frequencies of the oscillators.

* Supported in part by the National Research Council of Brazil during the summer of 1953, at the University of Sao Paulo, Sao Paulo, Brazil.

U5. A New Approach to the Classical and Quantum Theory of Many Interacting Particles. II. JEROME K. PERCUS, *Columbia University*, AND GEORGE J. YEVICK,* *Stevens Institute of Technology*.—We continue the discussion of the novel problems arising classically as well as quantum mechanically. Careful consideration must be given to a suitable selection of the Fourier coefficients representing the short-range potential inasmuch as only $3n$ Fourier terms are available. Moreover, one must reflect on the nature of the use of completely symmetric coordinates in dynamical theory. The collective coordinates are such that their domain of action is limited by the basic properties of the transformation. As regards the quantum-mechanical problem, new features are encountered: lack of uniqueness for the transition from the classical to the quantum-mechanical description; necessity for obtaining Fermi-Dirac or Einstein-Bose statistics using symmetric collective coordinates. The harmonic oscillators differ from those ordinarily met with in two respects; they are severely bounded in a manner depending upon f_k, ω_k, and q_k, and furthermore, both attractive and repulsive "elastic constants" prevail which appear to be essential to bring about crystallization. The only way to obtain the eigenfunctions and eigenvalues for the bounded oscillators is by means of perturbation methods. Finally, calculations are in progress for the evaluation of both the classical and quantum-mechanical partition functions.

* Supported in part by the National Research Council of Brazil during the summer of 1953, at the University of Sao Paulo, Sao Paulo, Brazil.

U6. Distortion of the Nucleus in μ-Mesic Atoms.* W. LAKIN AND W. KOHN, *Carnegie Institute of Technology*.—The ground-state energy of a mesic atom is lowered as a result of distortion of the nucleus by the meson. This energy shift, ΔE, was estimated by Cooper and Henley[1] for $Z=82$ as about 58 kev. We have calculated ΔE using in part empirical nuclear properties and find $\Delta E=16\pm8$ kev for $Z=80$ (ΔE varies slowly with Z). The remaining uncertainty in ΔE is very small; it corresponds to an uncertainty of only 0.2 percent in the nuclear radius and presents no serious obstacle to the determination of more detailed features of the nuclear charge distribution. The contribution to ΔE arising from virtual dipole transitions was calculated using the collective model of Jensen and Steinwedel.[2] The result, 7 kev, is much smaller than an estimate of 28 kev obtained by sum rules with neglect of correlation of the protons.

* Supported in part by the U. S. Office of Ordinance Research.
[1] L. Cooper and E. Henley, Phys. Rev. (to be published).
[2] H. Steinwedel and J. Jensen, Z. Naturforsh. **5a**, 413 (1950).

U7. The Lamb Shift in Mesic Atoms. H. C. CORBEN, *Carnegie Institute of Technology*.—Of the two radioactive corrections to the energy of a charged particle bound in an electrostatic field, the self-energy correction for a given unperturbed particle wave function is approximately inversely proportional to the square of the mass of the particle, whilst the vacuum polarization due to the field is approximately inversely proportional to the square of the mass of the electron. In contrast to the situation in ordinary atoms, the Lamb shift in mesic atoms therefore arises chiefly from vacuum polarization. The energy levels, especially those of S states, are thus depressed by this effect and if it is neglected the radius of the nuclear proton distribution, computed from the observed transitions to S states, is underestimated. Due to the smaller size of the mesic atom the effect is very much greater than in ordinary atoms. Even for a point nucleus, however, the percentage depression in the energy of an S state is approximately only $0.71\ \log_{10}(aZ/n^2)$ for $Z\gg n^2$, with $a=1$, 0.77 for π and μ mesons, respectively. With present experimental techniques the effect is therefore barely observable. In future more refined comparisons between nuclear force and electromagnetic measurements of nuclear radii it will be necessary to take it into account.

U8. Nuclear Charge Distribution. DAVID L. HILL, *Los Alamos Scientific Laboratory and Vanderbilt University* AND KENNETH W. FORD, *Los Alamos Scientific Laboratory and Indiana University*.—Mu-mesic x-rays, fast electron scattering, electronic x-rays, and electronic isotope shifts each depend on the nuclear charge distribution $\rho(\mathbf{r})$ in quite different ways. Adjoining theoretical analyses of observations on these different phenomena may therefore bracket an acceptable set of functional descriptions for $\rho(\mathbf{r})$. For several functional families representing conceivable forms for $\rho(\mathbf{r})$ we have obtained the resultant Coulomb potentials and have solved "exactly" by electronic computation the relativistic equations to yield the first four levels and transition energies for mu mesons bound in the field of the lead nucleus. These results permit adjustment of the effective nuclear radius R, for each form of $\rho(\mathbf{r})$ to agree with known x-ray measurements. Calculations completed for neighboring values of R will permit interpolation to improved values when corrections of the raw data for electrodynamic and special coupling effects are ultimately made. The second part of the program reported comprises the calculation by the exact phase-shift method of the angular dependence of fast electron scattering upon the different forms for $\rho(\mathbf{r})$, employing for each form the determined effective radius. Comparison of the model predictions with known observations, and looking apart from possibly small radiative and dynamic corrections, yields an indication of the charge distribution.

U9. Radiative Corrections to Electron Scattering. ROGER G. NEWTON,* *The Institute for Advanced Study.*—The second-order one-photon mass operator[1] has been applied to the calculation of the lowest-order radiative corrections to the second Born approximation[2] in the scattering of electrons by nuclei. The complete result, for a point source, is too complicated to be of practical value. The corrections are asymptotically (at high energies) proportional to the square of the logarithm of the energy. At about 100 Mev and for $\vartheta = 90°$, the leading term is several times larger than the uncorrected second Born approximation, but there may be cancellations with the next terms currently being calculated. Modifications (of the correction) due to the finite nuclear extension are probably small at energies of about 100 Mev, but they prevent it from diverging as the energy tends to infinity.

* Frank B. Jewett Fellow.
[1] R. G. Newton, (to be published).
[2] W. A. McKinley and H. Feshbach, Phys. Rev. **74**, 1759 (1948).

U10. High-Energy Events. JOSEPH V. LEPORE, MAURICE NEUMAN, AND RICHARD N. STUART, *University of California, Berkeley.*—The relative probabilities for alternate processes initiated by a nucleon-nucleon collision depend on the dynamics involved and on the volume in phase space accessible to each final state. According to arguments advanced by Fermi[1] the latter aspect alone may be of decisive importance when the energy of the colliding nucleons is very high. The assignment of relative *a priori* probabilities to the final states proportional to their extension in phase must be consistent with the translational, rotational, and Lorentz invariant properties of the colliding system. The latter in particular implies a conservation law for the center of energy $\Sigma(E_i r_i/C^2)$. Its effect is not only to lower the power of the configurational volume by one dimension but also to severely reduce the contributions from high momenta to the phase space integrals. The limitations on accessibility arising from the controllable constants of motion are not sufficient to insure well-defined probabilities. Some additional restriction on the configurational part of the phase space must be imposed. A cut-off factor of the form $\exp-[E_i^2 x_i^2/\hbar^2 C^2]$ for *each* particle is accordingly introduced. The configurational volume accessible to the particle thus decreases with increasing energy, a picture not inconsistent with the uncertainty principle. Some numerical results of this investigation will be presented.

[1] E. Fermi, Prog. Theoret. Phys. **5**, 4, 570 (1950).

U11. Restrictions on Invariant Transformation Groups in the Lagrangian and Hamiltonian Formalisms.* PETER G. BERGMANN, *Syracuse University.*—It is well known that quantum electrodynamics may be developed in several alternative forms, depending in part on the gauge transformation group with respect to which the theory is to be invariant. More generally, whenever a given theory is invariant with respect to a choice of representation or frame that depends on one or several arbitrary functions of space and time coordinates, such as the full gauge group, curvilinear coordinate transformations, and the like; it is possible to restrict the choice of frame by convenient conditions, known in relativity as coordinate conditions. In this paper it will be shown how under such a restriction, be it mild or be it so severe as to eliminate some of the original field variables, the conservation laws typical of invariant theories are preserved. In the Hamiltonian formalism we shall show how the constraints (the subsidiary conditions), which under the full group represent the extent of invariance, are modified and, under certain circumstances, partly eliminated.

* Supported by the U. S. Office of Naval Research.

SATURDAY AFTERNOON AT 1:45

Pupin 428

(J. H. VAN VLECK presiding)

Microwave Spectroscopy

V1. Microwave Spectrum of Methyl Amine.* DAVID R. LIDE, JR., *Harvard University.*—The absorption spectrum of methyl amine in the microwave region is complicated by the possibility of low-frequency internal motions in the molecule. In addition to hindered internal rotation about the C−N bond, such as occurs in methyl alcohol, an inversion of the type found in ammonia can take place. Thus a transition will generally involve changes in the torsional oscillation and inversion states as well as the change in over-all molecular rotation. The spectrum of methyl amine in the 15 000 to 35 000 mc region is currently being studied at Harvard[1] and at the University of Tokyo.[2] Some two hundred lines have so far been measured. Many of these lines fall into several well-defined series, which have been shown to correspond to $\Delta J = 0$ transitions in which the series members take on successive J values. In addition, several $\Delta J = \pm 1$ lines have been identified by means of the Stark effect. The assignments for these various lines will be discussed.

* Research supported by the U. S. Office of Naval Research.
[1] D. R. Lide, J. Chem. Phys. **20**, 1812 (1952); **21**, 571 (1953).
[2] Shimoda, Nishikawa, and Itoh, J. Phys. Soc. Japan **8**, 133, 425 (1953).

V2. The Microwave Spectrum of Ethyl Fluoride.* J. KRAITCHMAN† AND B. P. DAILEY, *Columbia University.*—A study of the microwave spectrum of ethyl fluoride has been undertaken because of its relevance to a number of problems of general interest. In particular, because of the possibility of hindered rotation about the C−C bond, analysis of the spectrum provides information pertaining to the magnitude of the potential barrier to such internal motions. While CH_3CH_2F is an asymmetric rotor its small asymmetry ($\kappa = -92$) and the absence of quadrupole hyperfine structure reduce the spectral complexity considerably. The spectrum was examined in the region from 17 to 38 kMc. The three rotational constants of the molecule were evaluated from analyses of the observed transition. By means of relative intensity measurements of rotational transitions in excited vibrational states the identification of a low-lying Raman frequency[1] as the torsional fundamental has been confirmed. This information plus a set of structural parameters obtained from the rotational constants of the molecule have allowed the hindering barrier height to be evaluated. The molecular dipole moment and its orientation in the molecule have also been determined.

* Work assisted by the U. S. Army Signal Corps and the Research Corporation.
† Present address: Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania.
[1] Smith, Saunders, Nielsen, and Ferguson, J. Chem. Phys. **20**, 847 (1952).

V3. The Microwave Spectrum of 1,1 Difluoroethane.* N. SOLIMENE AND B. P. DAILEY, *Columbia University.*—The spectrum of 1,1 difluoroethane has been investigated over the region 18 000 Mc to 38 000 Mc with a conventional Stark-modulation spectrometer. This molecule is a moderately asymmetric rotor of the oblate type with components of its dipole moment along the A and C axes. About 30 lines have been identified with the aid of the Stark effect and an approximate model for the molecule. The analysis yields the following rotational constants: $A=9491.95$ Mc; $B=8962.65$ Mc; $C=5170.43$ Mc; $H=0.75504$. These fit the observed frequencies to better than 0.5 Mc for transitions involving $J\mp3$. For higher J's the observed frequencies are fitted to within 5 Mc in most cases. The barrier hindering internal rotation has been determined as $(1.3\pm0.2)\times10^3$ cm^{-1} from intensity ratio measurements of the torsional frequency. The presence of an internal rotation hindered by a barrier of this magnitude apparently introduces no observable complications into the spectrum.

* Assisted by the U. S. Army Signal Corps and the Research Corporation.

V4. Hyperfine Structure in DCC, Cl, DCN, and HCN due to Deuteron Quadrupole Coupling and Field Asymmetries.* ROBERT L. WHITE, *Columbia University.*—The spectrum arising from the $J=1\rightarrow2$ transition in deuterated chloroacetylene has been observed in a high-resolution spectrometer and hyperfine structure due to the quadrupole coupling of the deuteron detected. A value for the coupling of $(eqQ)_D=+175\pm20$ Kc/sec was obtained, to be compared with -114 ± 1 Kc in HD obtained by molecular beam methods. The deuteron quadrupole coupling was also observed in transitions between 1-type doublets in DCN where an unresolved hyperfine structure resulted in line broadening. Comparison with unbroadened lines from HCN gave the less accurate but consonant evaluation $(eqQ)_D=\pm145\pm60$ kc/sec. Since the deuteron quadrupole moment is known, $(eqQ)_D$ yields an experimental value of the field gradient. The value thus obtained was compared with the gradient calculated from a Heitler London molecular model. The calculated value was too large and of the wrong sign, indicating the inadequacy of the model for this calculation. Asymmetry in the quadrupole coupling of N^{14} in the 1-type doublet transitions of HCN and DCN also produced hyperfine structure. From this structure, variations in the C−N bond due to bending can be detected.

* Work supported jointly by U. S. Army Signal Corps, U. S. Office of Naval Research, and the U. S. Air Research and Development Command.

V5. The Spin and Quadrupole Moment of Se^{75}.* L. C. AAMODT, P. C. FLETCHER, G. SILVEY, AND C. H. TOWNES, *Columbia University.*—The spin and nuclear quadrupole moment of radioactive Se^{75} have been determined from the microwave spectrum of $OCSe^{75}$. The Se^{75} was produced by the reaction $As^{75}(d,2n)Se^{75}$ using 22-Mev deuterons from the Brookhaven National Laboratory's cyclotron. The presence and abundance of Se^{75} in OCSe was determined by observing characteristic γ rays of this nucleus. Three lines of the quadrupole hyperfine structure of the $J=2\rightarrow3$ transition of $OCSe^{75}$ were observed. Their measured frequencies, relative intensities, and Stark patterns agree with a spin of 5/2 for Se^{75} and a quadrupole coupling constant of 946 Mc. This spin is not consistent with predictions from the single particle version of the shell model. The quadrupole coupling constant indicates the large positive quadrupole moment of 0.9×10^{-24} cm^2 for Se^{75}.

* Work supported by the U. S. Atomic Energy Commission.

V6. The Microwave Spectrum of ReO_3F.† J. F. LOTSPEICH AND ALI JAVAN, *Columbia Radiation Laboratory,* AND ALFRED ENGELBRECHT, *Temple University.*—The microwave absorption spectrum of ReO_3F has been observed for the rotational transitions $2\rightarrow3$ and $3\rightarrow4$. In addition to the lines originating from the ground vibrational state, a number of degenerate and nondegenerate excited vibrational state lines were found from which were obtained the vibrational and 1-type doubling constants. The quadrupole hyperfine structure due to Re was resolved. The following quantities have been calculated: $B_0=3566.751\pm0.050$ Mc; $eqQ_{Re}=-53\pm4$ Mc. The isotopic change of B_0 and of eqQ due to the two Re isotopes 185 and 187 is within the quoted errors. The 1-type doubling constants of two of the three degenerate vibration modes were found to be 4.82 and 16.35 Mc; their corresponding α_p values are $+2.64$ and -10.5 Mc, respectively. A value of α_p for a nondegenerate mode was measured as $+12.4$ Mc.

† Work supported by the U. S. Atomic Energy Commission.

V7. Microwave Spectrum of the Free OD Radical. G. C. DOUSMANIS, *Columbia University.*—A microwave spectrum resulting from the free $O^{16}D$ radical has been found with a Zeeman spectrometer similar to the one with which the OH spectrum had been observed.[1] The lines are due to transitions between the two members of the doublet resulting from the Λ-type splitting of each J-level in the ground paramagnetic state of the radical. The observed frequencies and their assignments are as follows:

K	J	Frequency (Megacycles)
5	$5\frac{1}{2}$	8 672.36±0.10
6	$6\frac{1}{2}$	12 918.01
7	$7\frac{1}{2}$	18 009.60
8	$8\frac{1}{2}$	23 907.12

The parameters describing the Λ-type doubling have been obtained as $4\Sigma(-1)^s(\Pi|ALy+2BLy|\Sigma)(\Sigma|BLy|\Pi)/V_{\Pi\Sigma}=2096\pm16$ Mc and $4\Sigma(-1)^s|(\Pi|BLy|\Sigma)|^2/V_{\Pi\Sigma}=-149.3\pm0.4$ Mc. These are in agreement with the values found in OH. The magnetic hyperfine structure in OD, in contrast to that in OH, is too small to be resolved (<3 Mc for $K=8$). This gives some information about the source of hyperfine structure in OH and OD.

* Work supported by the U. S. Army Signal Corps, the Office of Naval Research and the U. S. Air Force Research and Development Command.
[1] Sanders, Schawlow, Dousmanis, and Townes, Phys. Rev. **89**, 1158 (1953).

V8. Theory of the hfs of NO Molecule. MASATAKA MIZUSHIMA, *Duke University.*—The recent experimental results of Gordy and Burrus[1] on the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ lines of NO molecule in $^2\Pi_{\frac{1}{2}}$ state are explained satisfactorily. The formula $P\{F(F+1)-J(J+1)-I(I+1)\}+R\{(3/4)C(C+1)-J(J+1)I(I+1)\}$ was used with values of the constants as follows (in Mc):

J	1/2		3/2	
Λ doublet	c	d	c	d
P	−6.66	68.39	−8.61	21.40
R	0	0	0.77	0.035

Frosch and Foley's formula,[2] $P=a\pm b(2J+1)$, where the double sign corresponds to Λ-type doublet was found to be obeyed well. The ratio b/a is predicted by assuming a pure p state for the rotating electron to be 0.5, while the observed value gives 0.6. In $J=\frac{3}{2}$ state the $^2\Pi_{\frac{1}{2}}$ state contribute $+0.22$ Mc to P for both c and d states. The pseudo-quadrupole effect is found to be negligible. A new formula for the nuclear electric quadrupole effect was derived from which $eQ(\partial^2V/\partial z^2)$ was found to be -2.12 Mc. Another coupling constant was found from the difference of R between c and d states, and was explained by the p-electron approximation.

[1] W. Gordy and C. A. Burrus, Phys. Rev. (to be published).
[2] R. A. Frosch and H. M. Foley, Phys. Rev. **88**, 1337 (1952).

Post-Deadline Papers, If Any

SATURDAY AFTERNOON AT 1:45

Horace Mann

(D. ALPERT presiding)

Symposium of the Division of Electron Physics

Oxide-Coated Cathodes

W1. Review of Electronic Processes in BaO Crystals. R. L. SPROULL, *Cornell University.* (30 min.)

W2. The Conduction Mechanism in Oxide-Coated Cathodes. E. B. HENSLEY, *University of Missouri.* (30 min.)

W3. Review of Interface Compound Formation in Oxide Cathodes. E. S. RITTNER, *Philips Laboratories.* (30 min.)

W4. Noise Mechanisms in Oxide-Coated Cathodes. A. VAN DER ZIEL, *University of Minnesota.* (30 min.)

Business Meeting of the Division of Electron Physics

SATURDAY AFTERNOON AT 1:45

Pupin 301

(ENRICO FERMI presiding)

Neutron Physics

Invited Paper

WA1. Low-Energy Neutron Spectroscopy. W. W. HAVENS, JR., *Columbia University.* (30 min.)

Contributed Papers

WA2. Calculation of the Effect of Finite Resolution on the Neutron Transmission Near Resonance. E. MELKONIAN AND W. W. HAVENS, JR., *Columbia University.**—The effect of a triangular resolution function on the neutron transmission near resonance based on the Breit-Wigner formula with $\Gamma \ll E_0$ has been calculated analytically for the range of values of $n\sigma_0$ from 0 to 10 and resolution widths from 0 to 10 times the natural width of the level. An experimental transmission curve can be compared with this set of calculated curves to obtain approximate values of the level parameters. These calculations also give a relationship between σ_0 and Γ from the observed peak cross section, which can then be solved simultaneously with another relation between these parameters obtained by use of the area method.[1] Various relationships of interest, such as that between the maximum measured cross section and the sample thickness, with a given resolution, can also be obtained directly from these curves. These results are applicable only when the Doppler effect is small.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] Melkonian, Havens, and Rainwater, Phys. Rev. **92**, 702, 1953.

WA3. Tellurium Resonance Scattering.* H. L. FOOTE, JR.,† *Brookhaven National Laboratory.*—Scattering and total cross-section curves *versus* energy for the 2.33-ev resonance of tellurium have been observed. The scattering pipe technique of Borst[1] was used for the scattering measurements with a thin sample. The experimental data have been fitted to the one-level Breit-Wigner formula obtaining the following parameters: $E_0=2.33$ ev, $\sigma_p=4.61$ barns, $\sigma_0=668$ barns, $g=\frac{3}{4}(I=1)$, $\Gamma=0.114$ ev, and $\Gamma_n=0.0104$ ev. The method of analysis will be described which takes into account energy loss on scattering, Doppler broadening, instrument resolution, and the effect of sample thickness.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† Doctoral candidate from the University of Utah.
[1] L. B. Borst, Phys. Rev. **90**, 859 (1953).

WA4. Neutron Scattering by Rotators. A. C. ZEMACH AND R. J. GLAUBER, *Harvard University.*—Neutrons colliding with molecules at diffraction energies may exchange noticeable portions of their energy with molecular rotational modes. The difficulty in treating this inelasticity has been that for all save the lightest gases the collisions induce transitions between large numbers of angular momentum states. In the present work operator methods have been employed to find simple approximations for the required summations. For $\lambda/2\pi$ smaller than molecular dimensions, separate treatments are given for scattering at small and at large angles. Some of the features of the problem are illustrated by a model in which the scatterer is simply a mass point constrained to move on a sphere. The angle-dependent energy spectrum of the scattered particles may be easily found and integrated over energies. The resulting differential cross section decreases with increasing scattering angle. At large angles the cross section is less than the isotropic result obtained in the elastic approximation. The relative difference is of order m/M, the ratio of neutron mass to scatterer mass. Additional effects due to interference of scattering by different centers in an actual molecule are being treated by the same methods. The results will be discussed in relation to experimental work on neutron scattering by gases.

WA5. Gamma Rays Excited by the Inelastic Scattering of Fast Neutrons in Bismuth, Nickel, and Copper.* M. A. ROTHMAN, H. S. HANS,† AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Monochromatic neutrons of energy 3.8 Mev have been scattered in bismuth, nickel and copper. In NaI−Tl, gamma rays have been detected which are emitted in the inelastic scattering process. For bismuth the quantum energies are 0.91, 1.63, 2.60, and 3.35 Mev; for nickel 0.90 (?) and 1.36 Mev; for copper, ~0.9 Mev. Some additional data will be presented concerning zirconium and wolfram.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Fulbright Fellow, on leave of absence from the University of Aligarh, India.

WA6. Neutron Yields from $D-D$ Reaction in Various Target Materials.* R. C. CAMPBELL, J. D. KORSMEYER, AND D. C. RALPH, *Louisiana State University.*—The use of a Mobley magnet for producing short intense deuteron pulses, requires stopping beam on a baffle during the major part of each cycle. To determine the magnitude of neutron background arising from deuterium retained in such baffles, an investigation has been made of the neutron yields resulting from 100-kev deuterons incident on a number of materials. Tantalum, molybdenum, copper, aluminum, steel and graphite if maintained at room temperature show neutron yields which increase with time and reach saturation after a bombardment of the order of one coulomb/cm² of deuterons. Observed neutron yields range from 0.03 to 0.5 of that obtained from a thick heavy ice target. Self targets formed in this manner show no observable decay in twenty-four hours. All materials except graphite showed decreased neutron yields when run at higher temperatures. Tantalum and molybdenum run at about 800°C gave neutron yields less than 0.001 of that obtained from a thick heavy ice target. These metals are being further studied to determine optimum temperatures for the purpose of reducing neutron background from such baffles.

* Assisted by a grant from the Research Corporation.

WA7. Gamma-Gamma Coincidences from Interaction of 3.1 Mev Neutrons with Various Materials. V. E. SCHERRER, B. A. ALLISON, AND W. R. FAUST, *Naval Research Laboratory.*—Experiments have been performed to observe gamma radiation produced by bombardment of various materials with 3.1-Mev neutrons from the $D(d,n)He^3$ reaction. Coincidences between two gamma-ray detectors were used to trigger a twenty-channel pulse-height analyzer. Pulses from one detector were selected such that they corresponded to a single strong line, while the other detector recorded the complete spectrum on the analyzer. Gamma-gamma coincidence data were taken for zinc, chromium, and nickel.

WA8. Stern-Gerlach Experiment on Polarized Neutrons. J. E. SHERWOOD, T. E. STEPHENSON, C. P. STANFORD, AND SEYMOUR BERNSTEIN, *Oak Ridge National Laboratory.*—A Stern-Gerlach experiment has been carried out on a polarized beam of slow neutrons. The polarization was accomplished by reflecting pile neutrons from a magnetized iron mirror. Preliminary experiments, using the mirror as polarizer and a magnetized iron transmitter as analyzer, established that the direction of the polarization relative to the applied magnetic field for a reflector-type polarizer is opposite to that for a transmitter-type polarizer. The Stern-Gerlach apparatus will be described and curves will be presented which show the variation of intensity in the deflected beam with distance across the beam. These curves exhibit the velocity distribution and spin state for all neutrons present, as well as small effects ascribed to depolarization. Present results indicate that the sign of the polarization agrees with the theoretical prediction; namely, that for a transmitter-type polarizer, the spin-state of largest population has its spin oriented antiparallel to the applied magnetic field.

WA9. Interaction with Argon and Lead of Neutrons with Energies up to 2.3 Bev.* E. C. FOWLER, H. L. KRAYBILL, R. M. WALKER, AND R. S. PRESTON, *Yale University.*—The Yale magnet cloud chamber has been operated with the Brookhaven National Laboratory's cosmotron, utilizing the forward beam from 2.3 Bev protons incident on a beryllium target. Our expansion type chamber contained a one inch thick lead plate and was filled with argon. 1446 stereoscopic photographs of interactions between beam neutrons and the material in the chamber were obtained in four days of operation. Preliminary analysis of these photographs shows 87 "stars" of three or more prongs produced in the argon by neutral radiation. Their distribution by size is: No. of prongs: 3 4 5 6 7 8 9 ⩾ 10; No. of cases: 19 15 11 13 11 8 3 7. The decay of neutral V particles produced by beam particles has been observed.[1] Five examples appear to have been made in our lead plate. Details of their production and decay will be presented.

* Supported by the U. S. Atomic Energy Commission.
[1] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **90**, 1126 (1953).

WA10. Experiments with Neutrons from the Cosmotron I.* D. A. HILL,† T. COOR, W. F. HORNYAK,‡ L. W SMITH, AND G. A. SNOW, *Brookhaven National Laboratory.*—Experiments have been made to determine the nature and interaction cross section of high-energy neutrons from Be targets bombarded with 2.2 Bev protons. The neutrons are detected by requiring them to traverse an anticoincidence counter and produce in an Al radiator charged particles which penetrate 6 in. of Pb. The angular distribution of the neutrons from the target, the excitation curve of the detector, the γ-ray contamination of the neutron beam, and the angular distribution of charged secondaries from several elements will be discussed. A collimated beam of neutrons from a Be target is used to measure the transmission of various samples as a function of the detector geometry. The angular distribution of diffraction scattering in Pb and Cu indicates a mean neutron energy of 1.4 ± 0.2 Bev. With this beam, the total $n-p$ and $n-n$ cross sections were measured by CH_2-C and D_2O-H_2O difference experiments and found to be 44 ± 3 and $42\pm3\times10^{-27}$ cm², respectively.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Massachusetts Institute of Technology.
‡ Now on leave at Princeton University.

WA11. Experiments with Neutrons from the Cosmotron II.* G. A. SNOW, T. COOR, D. A. HILL, W. F. HORNYAK, AND L. W. SMITH, *Brookhaven National Laboratory.*—Using the apparatus described in I, transmission measurements have been made on Be, C, Al, Cu, Sn, and Pb as a function of the angle θ, subtended by the detector at the absorber. A rapid rise in transmission is found as θ varies from 0.22° ("good" geometry) to 6°–10° ("poor" geometry). The "poor" geometry points measure primarily the neutron absorption cross section, σa, while the "good" geometry points measure the sum of elastic diffraction scattering and σa. The cross sections measured in poor geometry after correcting for the residual diffraction scattering give the following values for σa in mb: 1610 Pb, 1220 Sn, 755 Cu, 446 Al, 231 C, 236 Be. The statistical accuracy in σa is 3–5 percent. Applying the optical model[1] for a uniform sphere and assuming that the bound and free $n-p$ and $n-n$ cross sections are equal, we determine the nuclear radius and the optical parameter (k_1/K) for each nucleus. The radii found for heavy elements are appreciably smaller than 1.40A¹.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

SATURDAY AFTERNOON AT 1:45

Casa Italiana

(M. G. WHITE presiding)

Plans for Accelerators of the Future

X1. Particle Orbits in the Alternating Radiant Synchrotron. E. D. COURANT, *Brookhaven National Laboratory.* (40 min.)

X2. Design of the 25-Bev Proton Synchrotron for the European Organization for Nuclear Research. J. P. BLEWETT, *Brookhaven National Laboratory* (consultant to CERN). (40 min.)

X3. Design Study for a 15-Bev Accelerator by the Cambridge Design Study Group. M. S. LIVINGSTON, *M.I.T.* (30 min.)

X4. Summary of Other Accelerator Studies in Progress. M. G. WHITE, *Princeton University.* (10 min.)

SATURDAY AFTERNOON AT 1:45

Schermerhorn 501

(N. M. KROLL presiding)

Theoretical Physics, IV

XA1. A Corrected Theory of Relativity and its Classical Interpretation. R. V. L. HARTLEY, *174 Summit Avenue, Summit, New Jersey.*—The application of modern knowledge of signal transmission to the light signals involved in the theory of relativity shows that its assumptions are not self-consistent. When they are made so, precise times of transmission can be deduced from the fundamental physical equations only by a linear approximation. This invalidates those conclusions which depend on the times being precise. Hence the electromagnetic equations are not consistent with the principle of relativity, the modified concepts of space and time which were thought to make this true have no particular significance, and the Lorentz invariance of a set of equations insures that they are *not* consistent with the relativity principle. This leaves the equations of Newtonian mechanics as the only ones known to be consistent with the principle. An ether model, consisting of a turbulent classical liquid with suitable constants, has been found to support mobile "standing" waves which, as models of material particles, exhibit the behavior required by "relativistic" mechanics. Here also a linear approximation is used. The mass of a particle is $1/c^2$ times its wave energy.

XA2. On Bohr's Theory of Energy Losses of Moving Charged Particles. JACOB NEUFELD, *Oak Ridge National Laboratory.*—The stopping power of a particle having charge $Z_{eff}e$ and moving with velocity v has been determined by Bohr for $\kappa = 2Z_{eff}e^2/hv > |$ and $\eta_s = 2v/u_s > 2$ where u_s is the velocity of the orbital electron that is effective in stopping the particle. Bohr's results are formulated differently for $\kappa/\eta_s < |$ and $\kappa/\eta_s > |$ and are based on an orbital picture of the processes involved. An alternative method has been developed in which the space surrounding the particle track has been subdivided into three regions: (a) the region of validity of the Rutherford formula (adjacent to the track), (b) the intermediate region involving large perturbations for which no adequate theory exists at the present time, and (c) the region of validity of the quantum perturbation theory (the most remote from the track). By extrapolating the formulas valid in regions (a) and (c) into the region (b), the contribution to the stopping power due to the region (b) has been estimated and adding to it the contribution due to the regions (a) and (c) an expression has been derived for the total stopping power that is applicable whenever $\kappa > |$ and $\eta_s > |$.

XA3. Time Reversal *vs* the Boltzmann Equation. J. S. LOMONT, *U. S. Naval Ordnance Test Station.*—The effect of time reversal on the solid state electronic Boltzmann transport equation has been investigated, and a simple formal mathematical transformation found which leaves it form invariant. The transformed variables can then be given physical significance in terms of a real reversed physical system. The reversion operator for the electron-phonon system in an external electric field can be explicitly constructed. The transformed distribution function must be interpreted as the distribution function for holes in the reversed system, and the transformed transition probability as the transition probability for holes. There is in fact a general relation between transition probabilities in forward and reversed systems (which does not hold for probabilities calculated by perturbation methods), whose fulfillment appears to depend on the vagaries of singular functions. The aforementioned formal transformation can then be interpreted as a time reversal transformation.

XA4. The Boltzmann Equation from the Statistical Mechanical Point of View.* MELVILLE S. GREEN, *University of Maryland.*—Recently Kirkwood and Green have given derivations of the Boltzmann equation from the so-called hierarchy of equations governing the distribution functions of n-uples of molecules. The present work will exhibit a derivation which is the first step of an expansion in powers of the concentration. If we call φ_n the distribution of the phases of an n-uple normalized so that the spacial distribution approaches 1 when all the molecules are far apart, it can be shown that for a spacially uniform situation the hierarchy can be written

$$\frac{d}{dt}\varphi_r = -c\sum_{i=1}^{n}\nabla_{p^i}\cdot\int \mathbf{F}_{in+1}\varphi_{n+1}d\mathbf{p}_{n+1}d\mathbf{x}_{n+1},$$

where the right-hand side is the total time derivative along a trajectory of an isolated system of n molecules, c the concentration, $\mathbf{F}_{in+1}$ the force between the ith and the $n+1$th molecule, and $\mathbf{p}_i$, $\mathbf{x}_i$ the momentum and position of the ith molecule. These equations are solved by considering the left-hand side to be a small perturbation. The first step in the procedure leads to the Boltzmann equation for φ_1 as well as to expressions for φ_n which are functionals of φ_1.

* This work supported by U. S. Office of Naval Research.

XA5. An Application of Group Theory to Statistical Mechanics. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—In calculating partition functions, one often combines complexions. Examples: indistinguishability of N particles coalesces $N!$ complexions into one, molecular symmetry σ (σ is the symmetry number). In every case (a) a set set of microscopic complexions corresponds to a macroscopic

state, the latter invariant under the group of all transformations of microscopic states into themselves, (b) subgroups exist with invariant subsets of complexions, (c) means for distinguishing between complexions in a subset are operationally undefined, (d) the number of complexions in the subset (its measure) is the symmetry number (generalized). The concept may be useful in crystal lattice theory.

XA6. Quantum Theory of the Radiation Resistance.* J WEBER, *University of Maryland.*—A previous paper[1] considered quantum effects in damping and noise. The vacuum fluctuations were shown to be observable in noise experiments. These results are extended to an electrical oscillator damped by a radiation resistance. First-order perturbation theory and the quantum statistics are employed. An expression is obtained, for the radiation resistance of a circuit, which is the same as the classical value. The damping and noise are the same as for other kinds of resistance.

* Supported by the U. S. Office of Naval Research.
[1] J. Weber, Phys. Rev. **90**, 977–982 (1953).

XA7. On Electromagnetic Scattering by a Paraboloid of Revolution.* CRAIGE SCHENSTED, *University of Michigan.* (introduced by K. M. Siegel).—On applying Kline's[1] asymptotic expansion to the scattering of a plane wave incident along the axis of a perfectly conducting paraboloid of revolution it was found that the series cuts off after only one term. It is readily found that the expression so obtained, namely

$$\mathbf{E}=\hat{\imath}\exp[i(kz-\omega t)]+\frac{R\exp[i[k(r-R)-\omega t]]}{r(1-\cos\theta)}\times(\cos\phi\theta'+\sin\phi\phi'),\dagger$$

is the *exact solution* of the above problem for the paraboloid $x^2+y^2=2Rz$. The result stated above is also precisely what would be given by geometric optics.

* Part of this paper appears in a larger report: UMM-115, "Studies in Radar Cross-Sections VIII, Theoretical Scattering Cross-Section as a Function of Angle at Small Wavelengths," K. M. Siegel, *et al.* (to be published).
† Primes were substituted for circumflex over theta and phi, since the printer does not have such symbols.
[1] Morris Kline, Commun. Pure and Appl. Math. **4**, 225 (1951).

XA8. Energy Equation for Sinusoidal Solutions of Maxwell's Equations with Electron Beams. PHILIP PARZEN, *The Johns Hopkins University.*—It is well known that the sinusoidal electromagnetic fields within a charge-free region are uniquely determined by specifying either the component of the electric field or the component of the magnetic field which is tangent to the boundary surface. The proof follows immediately from the conservation law for both real and reactive energy. A similar conservation law for both real and reactive energy is derived for the electromagnetic fields including electron beams if the sinusoidal current density is parallel to the sinusoidal beam velocity. The uniqueness theorem which follows from this conservation law states that the sinusoidal electromagnetic fields within a region are uniquely determined by specifying on the boundary surface the component of the sinusoidal electric field tangent to the surface, and either the sinusoidal electron velocity or the normal component of the sinusoidal current density.

XA9. Quantum Mechanics of the Scattering by a r^{-4} Attractive Potential. ERICH VOGT AND GREGORY H. WANNIER, *Bell Telephone Laboratories.*—The interaction potential of a charge carrier and a gaseous atom is at large distance attractive, varying as r^{-4}. This type of potential has, in classical mechanics, the simple property of yielding a constant "mean free time" between collisions—that is, a cross section varying inversely as the speed v. Among the various possible definitions of cross section, we picked the intrinsic cross section for spiralling orbits and investigated for it the modifications brought about by quantum mechanics. We find that the cross section oscillates about its classical value: $v^{\frac{1}{2}}(\sigma-\sigma_{\text{class}})$ varies essentially sinusoidally as a function of $v^{\frac{1}{2}}$. This can be understood qualitatively in terms of the allowed orbits in the old quantum theory. We know of no reason why there should not be a steady deviation of the cross section in addition to this oscillation. We have looked for this deviation with both analytical and numerical procedures and have failed to find it. We conclude therefore, tentatively, that the classical cross section is maintained exactly as the mean over a velocity cycle. One can show that, for very low speeds, the cross section approaches the double of its classical value. It is not clear at this time how this limiting case fits in with the properties already enumerated for larger speed.

XA10. Three-Dimensional Calculation of Vibrational Relaxation Times in Gases.* ROBERT N. SCHWARTZ, *Naval Ordnance Laboratory.*—Despite the simplified geometry of the one-dimensional collisions between a pair of molecules considered by C. Zener,[1] the calculations of vibrational relaxation times based on this method have been fairly successful.[2] Zener treated the collision problem by quantum mechanics but restricted the molecules to motion along a line. In the present paper the molecules are considered to move in three dimensions. The molecules are considered rotational with respect to the apse line. To a reasonable approximation the centrifugal force, in a given collision, only affects the solution by modifying the velocity at which molecules enter into the range of the repulsive molecular field but does not otherwise affect the transitional probability. The probabilities calculated by treating the collision as a straight line motion and summing over a one-dimensional velocity distribution give nearly the same results as obtained by treating the collision processes in three dimensions and summing over a spacial distribution of velocities.

* Doctoral dissertation, Catholic University, 1953.
[1] C. Zener, Phys. Rev. **37**, 556 (1931).
[2] Schwartz, Slawsky, and Herzfeld, J. Chem. Phys. **20**, 1591 (1952).

SATURDAY AFTERNOON AT 1:45

Havemeyer 309

(C. S. Wu presiding)

Beta and Gamma Emitters, II

Y1. The Inner Bremsstrahlung for Cs^{131}.* BABULAL SARAF,† *Bartol Research Foundation.*—The continuous gamma-ray spectrum associated with orbital electron capture in Cs^{131} has been studied with the aid of a scintillation spectrometer. From the end point, the disintegration energy of Cs^{131} is estimated to be 300±20 kev. Upper limits of 10^{-7} and 10^{-10} per disintegration are placed upon transitions leading to the excited levels of Xe^{131} of excitation energies 80 kev and 163 kev. Values of log ft calculated from the energy measurement and the estimates of intensities given above are in agreement with

orbital assignments of $d_{5/2}$ and $d_{3/2}$ for the respective ground states of Cs^{131} and Xe^{131}, $s_{1/2}$ for the excited level at 80 kev, and $h_{11/2}$ for the isomeric level of excitation energy 163 kev. The shape of the spectrum has been studied in detail and there is evidence that it is not in agreement with that predicted by the simple theory applicable to nuclei of low Z. The radiative capture probability of the decay process has been measured.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Research Fellow, Bartol Research Foundation; on leave of absence from Agra College, Agra, India.

Y2. The Nuclear Spectra of Ce^{144} and Pr^{144}. W. J. AUTH, W. S. EMMERICH, AND J. D. KURBATOV, *The Ohio State University.*—The radiations of Ce^{144} and Pr^{144} have been investigated with a magnetic lens spectrometer, a photographic spectrograph, and a scintillation spectrometer. The energies of the principal beta and gamma rays were measured and their relative intensities established. A Kurie plot analysis of the beta rays yielded an intensity of 70 percent for the 304-kev transition to the ground state of Pr^{144}. From an analysis of the gamma rays, an intensity of 22 percent was obtained for the transition leading to the 134-kev level and an intensity of about three percent for the 80-kev level. In the disintegration of Pr^{144}, the branching ratios were obtained by a comparison of the 2.98-Mev beta transition intensity with the 695-kev gamma ray. Applying the relative intensities of the gamma rays in Nd^{144} given by Alburger and Kraushaar, an intensity of 0.9 percent was obtained for the 2.2-Mev beta transition.

[1] D. Alburger and J. Kraushaar, Phys. Rev. **87**, 448 (1952).

Y3. The Disintegration of Sm^{153}. R. L. GRAHAM AND J. WALKER,* *Chalk River Laboratories.*—The radiations from Sm^{153} (47.0 hr) have been studied by β-ray spectrometers, scintillation spectrometers, and millimicrosecond coincidence techniques. Fermi analysis of the β-ray spectra above 350 kev has given three main components of end points 810 ± 10 kev (about 20 percent), 710 ± 15 kev (about 50 percent), 640 ± 15 kev (about 30 percent). The second of these has been shown to be in coincidence with the conversion electrons of a 69.0×0.4-kev γ ray and the third with conversion electrons of a 102.5 ± 0.5-kev γ ray. Weak γ transitions of 170 kev and 520 kev have also been observed. The conversion coefficient of $\gamma69.1$ has been measured as 5.7 ± 1.0 and the K/L ratio as >4.6; for $\gamma102.6$ the K/L ratio is ≥6.1. Delayed coincidence measurements between conversion electrons and β rays have given $T_{\frac{1}{2}}=(4.0\pm0.2)\times10^{-9}$ sec for the state at 102.6 kev and $T_{\frac{1}{2}}=(1.4\pm0.4)\times10^{-10}$ sec for the one at 171.6 kev. The conversion coefficients and K/L ratios show that both radiations are predominantly $M1$. It is interesting to note that the higher transition probability is associated with the lower energy.

* U. S. Atomic Energy Commission Laboratory, Postdoctorate Fellow, on leave of absence from the University of Birmingham, Birmingham, England.

Y4. Activation Measurements in Europium with Monoenergetic Neutrons.* R. E. WOOD,† *Brookhaven National Laboratory.*—Europium foils were irradiated with monoenergetic neutrons, using the Brookhaven National Laboratory crystal spectrometer. The 9.3-hour activity of Eu^{152} was observed as a function of neutron energy. It was thus possible to determine the isotopic assignment for several of the eight resonances, between 0.2 ev and 5.0 ev, found by Sailor.[1] The ratio of the 9.3-hour activity to the total cross section was observed to vary from resonance to resonance, which indicates that the isomeric state of Eu^{152} is being populated differently for each resonance. The isotopic assignment of the resonances will be given, and the variations in population of the isomeric state in Eu^{152} will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† Doctoral candidate from the University of Utah.
[1] V. L. Sailor (private communication).

Y5. Decay Scheme of the 5.5-Hr Isomer of Hf^{180m}.* J. W. MIHELICH, GERTRUDE SCHARFF-GOLDHABER, AND MICHAEL MCKEOWN, *Brookhaven National Laboratory.*—Recently,[1] theoretical considerations suggested the desirability of further study of the multipole character of the γ rays in Hf^{180m}. Previously only the 0.093-Mev transition was identified as electric quadrupole.[2] We measured the relative intensities of the unconverted γ rays of 0.442, 0.330, 0.214, and 0.093 Mev (energies quoted from Burson *et al.*)[2] by means of a NaI(Tl) scintillation spectrometer and found them to be compatible with the assumption of four $E2$ transitions. The γ rays were shown to succeed each other within less than a microsecond. The conversion electron spectrum obtained by a 180° magnetic spectrograph confirmed the above assignment and showed that the 0.0576-Mev transition is responsible for the 5.5-hr lifetime and is probably $M3$. Accurate energy determinations gave values of 93.3, 216.0, 332.4, and 443.6 kev, in good agreement with Bohr and Mottelson's formula. Angular correlation measurements are in progress.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] A. Bohr and B. R. Mottelson, Phys. Rev. **90**, 717 (1953).
[2] See M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

Y6. A 10.5-Day Isotope of Platinum.* R. A. NAUMANN, *Princeton University.*—Metallic iridium has been irradiated with 50-Mev protons in the Columbia and Harvard University synchrocyclotrons and a platinum fraction has been chemically isolated from the bombarded targets. The decay of the platinum fractions has been observed employing end-window Geiger counters and shows a 10.5-day period which has been followed for 60 days. An iridium fraction showing a 40-hour decay component has been isolated from the 10.5-day platinum while the latter fraction, after repurification, shows an increase in activity compatible with the growth of a 40-hour daughter. A mass assignment of 188 to the platinum activity is supported by a previous assignment of a 41-hour iridium activity as iridium 188.[1] Several conversion electron lines have been found to be associated with the decay of the platinum activity. Further studies on the decay schemes of these activities are continuing.

* This work was supported by the U. S. Atomic Energy Commission, The Higgins Scientific Trust Fund, the U. S. Office of Naval Research, and in part by a grant in aid of the E. I. Dupont de Nemours Company.
[1] T. C. Chu, Phys. Rev. **79**, 582 (1950).

Y7. Decay of Pt^{191}.† E. P. TOMLINSON AND R. A. NAUMANN, *Princeton University,* AND J. W. MIHELICH, *Brookhaven National Laboratory.*—Samples of 3-day Pt^{191} (and 4-day Pt^{193m}) have been obtained by bombarding Ir with deuterons in the Brookhaven cyclotron and studied with a gray-wedge coincidence analyzer[1] and 180° photographic spectrographs at Brookhaven and with the Princeton high-resolution Siegbahn-type spectrometer. We find the γ rays of 82, 96, 125, (135 from Pt^{193m}), 172, 179, 268, 350, 360, 409, 456, and 540 kev as reported by Swan, Portnoy, and Hill.[2] Conversion electrons which would give rise to the 62-kev transition reported by these authors, we believe to be Auger electrons. We also find evidence for γ rays of 42, 220, approximately 620, and possibly 158 kev. From the energies, the conversion electron and γ-ray intensities, and the coincidence measurements of these γ rays, a self-consistent energy-level scheme can be proposed for Ir^{191}. Work is continuing on these measurements.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] Bernstein, Chase, and Schandt, Rev. Sci. Instr. **24**, 437 (1953).
[2] Swan, Portnoy, and Hill, Phys. Rev. **90**, 257 (1953).

Y8. Resonance Fluorescence with Nuclei: Hg^{199}.* F. R. METZGER AND W. B. TODD, *Bartol Research Foundation.*—The decay of Au^{199} proceeds partially through a 209-kev excited state of Hg^{199}. The 209-kev transition to the ground state of Hg^{199} has been used to excite Hg^{199} nuclei contained in a

mercury absorber. The thermal motion in the Au^{199} source provided the velocities necessary to compensate through Doppler effect for the energy loss which the gamma rays suffer in the emission and absorption processes. When the source is heated, the contribution due to resonance fluorescence increases. From the observed change one calculates a lifetime of $(3.1\pm0.9)\times10^{-10}$ sec for the 209-kev transition in Hg^{199}, assuming isotropic distribution for the $M1$ transition of unknown $E2$ admixture. The observed value has to be compared with the upper limit of 3.4×10^{-10} sec found with electronics[1] and with a value of 3.6×10^{-12} sec estimated from Weisskopf's lifetime formula.[2]

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bell, Graham, and Petch, Can. J. Phys. **30**, 35 (1952).
[2] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).

Y9. Nuclear Energy Levels of Tl^{203}.† JAGDISH VARMA,* *Bartol Research Foundation.*—Using scintillation counting techniques, Pb^{203} is found to decay by K capture to the 683- and 280-kev excited levels in Tl^{203}. In addition to the 403- and 280-kev cascade gamma rays, the 683-kev cross-over transition is also observed. Careful energy measurements showed, in contrast with earlier results, that the same 280 ± 1 kev level of Tl^{203} is excited in decay of both Hg^{203} and Pb^{203}. Conversion coefficient measurements of the 280-kev quantum support this conclusion. The K-shell conversion coefficient of the 403-kev gamma ray is measured as 0.052 showing the transition to be a mixture of 87 percent $E2$ and 13 percent $M1$. The K/L ratio also indicates the same admixture of $E2$ in $M1$. The observed facts agree with orbital assignments of $d_{5/2}$, $d_{3/2}$, and $s_{1/2}$ for the levels of Tl^{203} in order of decreasing excitation energy, and of $f_{5/2}$ for the ground state of Pb^{203}. Angular correlation measurements give the anisotropy expected for a mixture-mixture correlation with mixing ratios as deduced from the conversion measurements.

† Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* Research Fellow, Bartol Research Foundation; permanent address Morena (M.B.) India.
[1] G. D. O'Kelley, Ph.D. thesis, University of California. Unclassified Report URCL-1243 (May, 1951).

Y10. Energy Levels of Pb^{209}". L. G. ELLIOTT, R. L. GRAHAM, J. WALKER, AND J. L. WOLFSON, *Chalk River Laboratories.*—Measurements have been made of the K internal-conversion coefficients of the 2.62-, 0.583-, 0.860- and 0.511-Mev γ-ray transitions in Pb^{208} and also of the angular correlations between pairs of these γ rays selected by NaI(Tl) scintillation spectrometers. These results lead unambiguously to the spin and parity assignments of 0+ (assumed), 3-, 5-, 4- and 5- for the ground, 2.62-, 3.20-, 3.48-, and 3.71-Mev levels, respectively. The measured values of α_K are $(1.78\pm0.12)\times10^{-3}$ for $\gamma2.62$ and $(1.58\pm0.11)\times10^{-3}$ for $\gamma0.583$ which are in good agreement with the theoretical values for $E3$ and $E2$, respectively. The $\gamma2.62$–$\gamma0.583$ angular correlation has been studied in detail using liquid sources because of the reduced anisotropy found with solid sources. The results agree well with the (0–3–5) assignment and reject the previously proposed assignments of (0–1–3) or (0–2–4). Other correlation and conversion measurements indicate for $\gamma0.511$, an intensity ratio $E2/M1=1.7\pm0.3$ with 0° phase difference, and for $\gamma0.86$ $E2/M1=(6.5\pm6.5)\times10^{-4}$ with 180° phase difference. Delayed coincidence measurements yield half-lives of $(2.4\pm1.0)\times10^{-10}$ sec for the 3.20-Mev level and $<10^{-10}$ sec for the levels of 2.62 and 3.71 Mev.

Y11. New Method for Measuring Short γ-Ray Lifetimes. J. W. KNOWLES, *Chalk River Laboratories.*—A method for the measurement of short γ-ray lifetimes less than 10^{-12} sec is presented with particular reference to the 0.239-Mev γ ray of Bi^{212} following the β decay of Pb^{212}. The method consists of measuring the rms recoil displacements of active atoms following β emission. The active atoms occupy regular positions in a crystal lattice before emission. The recoil atoms if still in an excited state may emit a γ ray within the time of flight or time of oscillation of the atom. A fraction of these γ rays is internally converted producing x-rays which diffract from the crystal lattice as Kossel cones.[1] The intensity of these cones relative to their background is dependent on the position of the recoil atoms in the crystal unit cell when γ-ray emission occurs. A preliminary measurement of the half-life of the 0.239-Mev γ ray of Bi^{212} gives a value between the limits 10^{-12} to 10^{-14} sec. An estimate of about 10^{-12} sec for the life-time of this γ ray using K/L ratio data has been reported.[2]

[1] Z. Physik **94**, 139 (1935).
[2] Can. J. Phys. **31**, 377 (1953).

Y12. Gamma-Ray Spectrum of a Po–B Source. TEMPLE LOVE AND FRED MAIENSCHEIN, *Oak Ridge National Laboratory.*—Specta have been measured of the gamma rays emitted from excited levels in nitrogen as produced in the reactions $B^{10,11}(\alpha,n)N^{13*,14*}$ employing polonium alpha particles. The spectrometers used were a single-crystal (NaI) scintillation spectrometer and a 3-crystal pair spectrometer. The high-energy portions of the spectra were investigated with the source and detector suspended in air (~8 ft to the nearest wall) in order to lower the neutron capture gamma-ray background. A 6-in. lead shield was used to reduce the background in the low-energy regions. The polonium activity of the Po–B source was compared with the activity of a Po–Be source by measuring the relative strengths of the 0.803-Mev polonium gamma ray. Then the intensities of the Po–B gamma rays were determined and are reported here as percentages of the intensity of the 4.43-Mev gamma ray from a Po–Be source of the same Po activity. Energy calibrations were made using this same 4.43-Mev gamma ray. The results were: 2.27 Mev (6.8 percent), 3.03 Mev (1.5 percent), 3.59 Mev (6.8 percent), 5.95 Mev (~0.13 percent), and 7.7 Mev (~0.09 percent).

Y13. The Spin of RaE.* R. W. KING, *National Research Council,* AND D. C. PEASLEE, *Columbia University.*—The following evidence suggests $I=1^-$ for the ground state of RaE: (a) throughout the periodic table, $\Delta I=1$ (yes) transitions have ft values an order of magnitude larger than for corresponding $\Delta I=0$ (yes), indicating partial cancellation of large terms of order $(\alpha Z/2\rho)^2$, which make 1st forbidden spectra appear straight; (b) in the "favored" 1st forbidden region around $A=208$, the $\Delta I=0$ (yes) transitions (including 3 probable $0\rightarrow0$ cases) have log ft ≈ 5–6, as in RaD→RaE*; (c) the α decay[1] of RaE is most consistent with the lifetime energy relationship if its final state is Tl^{206*}, implying $I(\text{RaE})\neq I(Tl^{206})=0^-$. The evidence against $I=1^-$ and favoring $I=0^-$ for RaE is not conclusive: (a) several heavy nuclei show exceptions to Nordheim's rule forbidding 1^- ground state; (b) the state $(h_{9/2}\ g_{9/2})_1$ has $\mu_{\text{calc}}=0.08$ nm, probably below the limit of spectroscopic resolution; (iii) the RaE β-spectrum shape can be fitted with $\Delta I=1$, yes, as well as $\Delta I=0$, yes.[2]

* This work partially supported by the U. S. Atomic Energy Commission.
[1] E. Broda and N. Feather, Proc. Roy. Soc. (London) **A190**, 20 (1947).
[2] M. Yamada, Abstracts of Tokyo Conference, A 93 (1953).

Y14. Rates of Decay of the Observed Anisotropies in the Am^{241} $\alpha-\gamma$ and Cd^{111} $\gamma-\gamma$ Angular Correlations. J. S. FRASER AND J. C. D. MILTON, *Chalk River Laboratories.*—Observations were made of the anisotropy $A=[W(\pi)]/[W(\pi/2)]-1$ as a function of delay between the first and second radiations of the cascade. The delayed coincidence circuit had a resolving time of about 1.5×10^{-8} sec which is shorter than the half-lives of the intermediate states in Np^{237} (6×10^{-8} sec) and Cd^{111} (8×10^{-8} sec). The anisotropy observed in a solid source of Am_2O_3 had an initial value $A=-0.15\times0.03$ but decayed with a half-life of about 5.5×10^{-9} sec to

$A \approx 0$ after 2×10^{-8} sec. The polarization of the 60-kev γ ray as measured at 110° from the α particle exhibited a comparable rate of decay from an initial value $N_{11}/N_{\perp}=0.81\pm0.04$. Cd^{111} was investigated in solid sources of $InCl_3$ and In_2O_3 and in a dilute aqueous solution of $InCl_3$. The anisotropy in $InCl_3$ and In_2O_3 had initial values -0.27 ± 0.04 and -0.24 ± 0.04, decay half-lives $(10.0\pm5)\pm10^{-9}$ sec and $(7.5\pm4)\pm10^{-9}$ sec, and final values -0.028 ± 0.01 and -0.082 ± 0.01, respectively. The liquid source, as expected, gave a constant anisotropy $A=-0.215\pm0.01$ over the measured range of 7×10^{-8} sec.

SATURDAY AFTERNOON AT 1:45

McMillin Theatre

(G. T. REYNOLDS presiding)

Cosmic Rays and Diverse Particles

Invited Papers

Z1. Cosmic Radiation at Very High Altitudes Near the Geomagnetic Equator. W. A. POMERANTZ, *Bartol Research Foundation.* (30 min.)

Z2. Properties of New *V* Particles. E. W. COWAN, *California Institute of Technology.* (30 min.)

Contributed Papers

Z3. The Flux of Primary Cosmic-Ray Alpha Particles.* JOHN LINDSLEY, *University of Minnesota.*—A cloud chamber-Čerenkov counter apparatus was flown by Skyhook balloon for five hours at an atmospheric depth 17 g/cm². The chamber was triggered by sufficiently large pulse from a thin Čerenkov counter in coincidence with a gate from a geometry-defining G-M counter telescope. Of 157 photographs, 60 show the track of a counter age alpha particle within the proper solid angle. Twenty show the track of a fast particle with $Z>2$. The pulse-height requirement implied an energy threshold at 700±100 Mev/nucleon for alpha particles (extrapolated to the top of the atmosphere). If it be assumed that all of the alphas were primary and that primary alphas are effectively absorbed in nuclear collisions with geometric cross section, the vertical flux of primary alpha particles above the threshold energy is 0.014 ± 0.002/sec cm² steradian.

* The research was supported in part by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

Z4. Mapping Particle Paths in Earth's Magnetic Field. WILLARD H. BENNETT, *Naval Research Laboratory.*—In the course of an investigation of magnetically self-focusing streams as the mechanism responsible for producing auroral streams,[1] a model has been built with which to observe the paths of charged particles in the earth's magnetic field. Braun-tube type streams are produced in a tube, the inside of which has been made conductive by Clark's process.[2] The tube is transparent, permitting clear observation of the orbits. A bar magnet inside an aluminum sphere represents the earth. The system constitutes a true model of orbits in the earth's field except for one minor correction.

[1] Phys. Rev. **91**, 1562 (1953).
[2] Rev. Sci. Instr. **24**, 641 (1953).

Z5. The Influence of the Earth-Magnetic Field on Extensive Air Showers. GIUSEPPE COCCONI, *Cornell University.*—The lateral displacement from the rectilinear path, D_m, resulting from the influence of the earth-magnetic field on the electrons in an extensive air shower has been evaluated in first approximation and found of the same order of magnitude as the displacement, $(\langle D_s^2\rangle_{Av})^{\frac{1}{2}}$, produced by Coulomb scattering. For electrons above critical energy, arriving in vertical direction, $D_m/(\langle D_s^2\rangle)^{\frac{1}{2}}=0.45\cos\lambda/P$, ($\lambda$ = geomagnetic latitude, p = air pressure in atmos). It seems that this effect has been overlooked by the several authors who calculated the electron lateral distribution in extensive showers. At sea level and moderate latitudes, the distribution around the core of the electrons above critical energy is, roughly speaking, elliptical rather than circular, with the major axis in the $E-W$ direction and about two times larger than the minor axis. The deviations from circular symmetry are presumably smaller for electrons below critical energy, where the effect of large, single scatterings becomes important, and for the other components of the shower (mesons and nucleons), owing to their large angle of production. These considerations will make even more difficult the interpretation of the experiments on the distribution around the core of high-energy electrons.

Z6. Time Structure of Extensive Air Showers.* R. SUGARMAN AND S. DE BENEDETTI, *Carnegie Institute of Technology.*—The difference in time between the pulses of two liquid scintillation tanks (A: 0.17 m²; B: 0.11 m²; 1.3 m apart; 390-m elevation) was measured whenever their pulses were in quadruple coincidence with two unshielded Geiger tube trays (0.20 m²; 3.9 m apart) for the three following experimental conditions: (I) no shielding; (II) no shielding but 85 percent of tank A-area made inoperative with opaque paper cover; (III) paper removed, tank A shielded with 8-in. Pb. Root mean square deviations, including instrumental errors, were never larger than $6\cdot10^{-9}$ sec. A significant increase (from 3 to $6\cdot10^{-9}$ sec) was observed in the order (I), (II), (III). This result is attributed at least in part to variations in the detected particle density of the tanks, as will be discussed. Increase with shielding of mean delay time of tank A relative to B was $1\pm1\cdot10^{-9}$ sec, indicating that no delays between soft and hard particles were resolved by this experiment.

* Supported in part by the U. S. Atomic Energy Commission.

Z7. Distribution of Specific Ionization of Primary Cosmic Rays at $\lambda=10°$N.* G. W. MCCLURE, *Bartol Research Foundation.*—A balloon-borne instrument comprising a G-M counter train with an interposed fast-ionization chamber has been flown at $\lambda=10°$N for the purpose of determining the distribu-

tion of specific ionization of relativistic primary cosmic rays. The ion-chamber pulse coincident with each counter telescope traversal was recorded on a continuously moving film and was specially labeled if accompanied by the discharge of 2 or more counters in a 7-counter horizontal shower tray directly under the chamber. Sea-level calibrations indicated that monoenergetic primary protons should yield a peaked differential pulse-height distribution with a 20 percent width at half-maximum, and that monoenergetic primary α particles should yield a peak of similar shape with a most-probable pulse height approximately 4 times that for protons. Data obtained in a 5-hour level flight at 12 mm Hg indicated a large peak corresponding to relativistic singly-charged particles but no pronounced peak attributable to α's. Of those pulses greater than 3 times minimum ionization—which comprised 40 percent of the total number of events and presumably include the entire α component at this altitude—nearly 70 percent were accompanied by shower indications.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

Z8. The Energy Distribution of Neutral Mesons Produced in Cosmic-Ray Stars.* Y. B. KIM,† *Princeton University.*—The final result of a cloud-chamber experiment to study the energy distribution of π^0 mesons produced in cosmic-ray stars will be reported.[1] In estimating the energy of a photon from its shower, the maximum number of electrons observable, n_{max}, was used. An investigation shows that n_{max} is a good index in spite of fluctuations. The fluctuation at the cascade maximum $\bar{n}_{(t\ max)}$ comes from: (a) the fluctuation in the absolute maximum, and (b) uncertainty as to where this maximum occurs. To study these two kinds of fluctuations separately, R. R. Wilson's shower sheets were used. The distribution in n_{max} is much narrower than that in $\bar{n}_{(t\ max)}$, as seen in Table I.

TABLE I. Numbers of electrons of energy $\geqslant 8$ Mev. $\delta = \{\langle (n-\bar{n})^2 \rangle_{Av}\}^{\frac{1}{2}}/\bar{n}$.

Photon energy	$\bar{n}_{(t\ max)}$	δ	$\bar{n}_{max}$	δ
50 Mev	0.49	1.59	1.34	0.451
100 Mev	0.88	1.12	1.92	0.282
300 Mev	2.13	0.701	3.66	0.342

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Department of Physics, Indiana University.
[1] Y. B. Kim, Phys. Rev. **91**, 445 (1953), gives preliminary results.

Z9. Gamma Rays Associated with *S*-Particle Decay.* H. COURANT.—Two additional cases of electron cascades associated with *S*-particle decays have been observed in the M.I.T. cloud chamber at Echo Lake, Colorado. In the four cases previously reported,[1] the direction of propagation of the cascades appeared as opposite to that of the charged decay product. The two new events are of special interest because in each case the electron cascade is not co-linear with the direction of the charged decay product. The probability that these events are a result of chance coincidence between an *S* particle and an electron cascade is small. Individual cases will be discussed.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bridge, Courant, DeStaebler, and Rossi, Phys. Rev. **91**, 1024 (1953).

Z10. Unstable Heavy Particles from the Cosmotron.* R. D. HILL, E. O. SALANT, AND M. WIDGOFF, *Brookhaven National Laboratory;* L. S. OSBORNE, A. PEVSNER, AND D. M. RITSON, *M.I.T.;* J. CRUSSARD AND W. D. WALKER, *University of Rochester.*—Ilford G5 emulsions were bombarded by 1.5-Bev negative pions, magnetically analyzed after emerging from the Brookhaven cosmotron. In the scanning of 3.5 cm³ of emulsion, two heavy decaying particles were observed, both emerging from stars with a minimum track in the collimated beam. One large star shows a backward heavily-ionizing particle of range 9 mm, which stops and emits a fast particle giving a steep, light track, roughly minimum. From preliminary measurements of range and scattering, the heavy particle has a mass of $850 \pm 200\ m_e$, typical of a *K* meson. One heavy prong of a 6-pronged star has a 260μ range and is probably the result of an alpha particle (but possibly to Li^{++}), which stops and decays into 3 coplanar tracks: (a) a gray, which grain count and scattering show is due to a 25-Mev pion; (b) a 5.3-Mev proton of 196μ range; (c) a 13μ track consistent with a 3.5-Mev He^3. With these masses and energies, co-planar momenta balance. Assuming the event is a decay of a V_0^1 of 37-Mev *Q* bound in an alpha particle, the binding energy of the V_0^1 is 4 Mev, compared with 20-Mev neutron binding.

* This work was supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

Z11. Kinematics of Λ^0 Production.* GEORGE T. REYNOLDS AND S. B. TREIMAN, *Princeton University.*—Cloud-chamber observations indicate that an appreciable fraction of Λ^0 particles resulting from cosmic-ray interactions in heavy elements (lead and copper) are produced at low energies in the laboratory frame.[1] At least 10 percent of the observed Λ^0 particles are produced at energies below 70 Mev. The cloud-chamber bias against observing high-energy Λ^0 particles, however, is probably not serious up to at least several Bev. We have considered the kinematics of a variety of fundamental reactions which might lead to Λ^0 production, taking into account the internal motion of the target nucleons in the nucleus. For the reactions considered, the above observations would imply that, in the center-of-mass system of the collision, Λ^0 production is peaked in the backward direction. In particular, if the bulk of the Λ^0 particles are produced in the reaction observed at Brookhaven:[2] $\pi + n \rightarrow \Lambda + K$ (where *n* is a nucleon and *K* is a particle of intermediate mass), the peaking in the backward direction must be extremely marked.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Ballam, Harris, Hodson, Rau, Reynolds, Treiman, and Vidale, Phys. Rev. **91**, 1019 (1953).
[2] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **91**, 1287 (1953).

Z12. A Search for *K* Particles Using Čerenkov Counters.* J. W. KEUFFEL† AND L. MEZZETTI,‡ *Princeton University.*—Two directional Čerenkov counters (*C*)[1] are mounted below a large liquid scintillator (*S*). The counters are surrounded by a Pb house with Al lining. The Čerenkov radiator is water in Lucite containers, painted black below and viewed from above by C-7157 photomultipliers. The measured efficiency for detecting downward relativistic particles is 2 percent; for upward particles, it is 90 percent; nonrelativistic particles ($E < \frac{1}{2}MC^2$) are not detected. This arrangement should permit precise time-measurements on the upward-going relativistic secondaries of *K*-particles unobscured by time-zero pulses from downward-going particles produced in the same event. The distribution of delays between *S* and *C* consists of a peak at time zero and a ~5.0-mμsec exponential extending over four mean lives. The measured timing error distribution of the counters and chronotron timing circuit is approximately Gaussian with s.d. 2 mμsec. The 5-mμsec component disappears when *C* is displaced 70 cm laterally (but still under 20 cm of Pb). Further tests to verify the identify of the 5-mμsec lags are proceeding.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at University of Utah.
‡ On leave from University of Rome.
[1] J. Winckler and K. Anderson, Rev. Sci. Instr. **23**, 765 (1952).

SUPPLEMENTARY PROGRAMME

SP1. Virtual States of Two Meson Systems. R. ARNOWITT, *University of California, Berkeley,* AND S. DESER, *Institute for Advanced Study.**—Bound and metastable states of two mesons have been studied with an approximate equation derived from the relativistic one satisfied by the two meson Green's function,

$$\mathcal{G} = -\langle(\phi_i(\xi)\phi_j(\eta)\phi_{i'}(\xi')\phi_{j'}(\eta'))_+\rangle + \langle(\phi_i(\xi)\phi_j(\eta))_+\rangle\langle(\phi_{i'}(\xi')\phi_{j'}(\eta'))_+\rangle.$$

The equation for $\mathcal{G}$ may be written in the form[¶]

$$[(k_1^2+\mu^2)(k_2^2+\mu^2)-I_{12}]\mathcal{G} = \delta_{ij'}\delta_{jj'}+\delta_{ij}\delta_{ji'},$$

I_{12} being the interaction kernel. To lowest (g^4) order, I_{12} has a contribution only from the four-sided "box" diagrams (scattering of mesons by mesons). For the corresponding homogenous equation, which yields the energy eigenstates of the system, the adiabatic limit of the lowest order interaction was used to derive a three-dimensional Schroedinger equation in relative coordinates. For the isotopic spin 1 state, there are no renormalizations of the $\lambda\phi^4$ type. Considering angular momentum $l \geq 1$, the resulting potential was treated approximately, use being made of the great strength and short range ($\sim\frac{1}{2}$ m) of one of its factors. A search is being made for metastable and bound solutions of the simplified equation, with particular reference to the possibility of representing the V_2^0 particle in this fashion, and results will be reported.

* To be called for at the end of Session B if the Chairman rules that time permits.

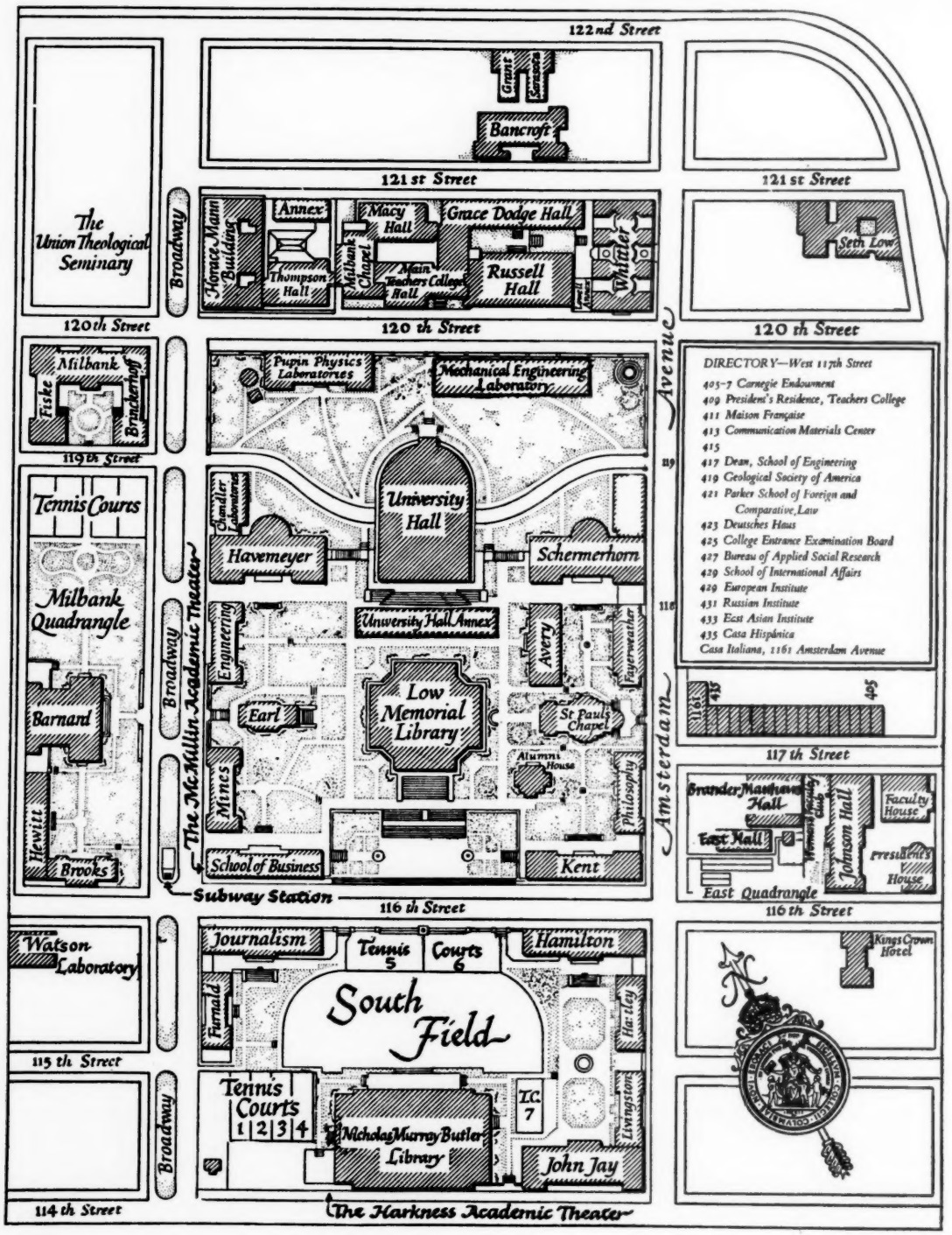
Author Index to Papers Presented at the 1954 Annual Meeting

Aamodt, L. C., P. C. Fletcher, G. Silvey, and C. H. Townes—V5
Albrecht, H. O. and C. E. Mandeville—QA2
Alford, W. Parker and Donald R. Hamilton—R5
Anderson, James L.—B3
Arnowitt, R. and S. Deser—SP1
—— and S. Gasiorowicz—B6
Arrott, A.—RA7
Aschner, J. F.—M8
Auth, W. J., W. S. Emmerich, and J. D. Kurbatov—Y2
Azumi, K. and J. E. Goldman—RA6
Bay, Z., V. P. Henri, and F. McLernon—R8
Bayard, Robert T. and J. L. Yntema—H3
Belinfante, F. J.—B2
Bemski, G., W. A. Nierenberg, and H. B. Silsbee—L6
Benedict, W. S. and Shirleigh Silverman—E9
Bennett, Willard H.—Z4
Bergmann, Peter G.—U11
Bernstein, Eugene—PA7
Betchov, R.—S9
Bichsel, H. and R. F. Mozley—JA8
Binger, D. and W. J. Sturm—I7
Bittner, J. W., R. G. Herb, R. D. Moffat, and J. A. Weinman—LA7
Blewett, J. P.—X2
Block, R. C., J. H. Gibbons, E. G. Bilpuch, and D. F. Herring—PA2
Bockelman, C. K. and J. J. Jung—C7
Boorse, H. A.—N2
Braams, C. M.—JA1
Bradshaw, B. C. and R. A. Shuttleworth—F2
Brattain, W. H. and C. G. B. Garrett—D8
Bray, P. J.—L1
Breit, G.—LA4
Bridgman, P. W.—I1
Brockhouse, B. N.—RA5
Brockman, Karl W., Jr.—T3
Burstein, E., B. W. Henvis, and N. Sclar—D9
Caird, R. S. and Allan C. G. Mitchell—R13
Campbell, R. C., J. D. Korsmeyer, and D. C. Ralph—WA6
Case, K. M.—U3
Caswell, R. S., R. F. Gabbard, W. P. Doering, and D. W. Padgett—T11
Chen, F. F., C. P. Leavitt, and A. M. Shapiro—T1
Christian, R. H. and Robert G. Schreffler—S10
Church, E. L. and J. E. Monahan—IA6
Clark, David D. and Owen Chamberlain—T2
Class, C. M., C. F. Cook, and J. T. Eisinger—C3
Clauser, Francis H.—S8
Cocconi, Giuseppe—Z5
Cohen, B. L.—O1
——, W. H. Jones, G. H. McCormick, and B. L. Ferrell—H10
Collins, G. B.—A1
Coon, J. H. and R. W. Davis—T7
Corben, H. C.—U7
Corrsin, Stanley—S7
Cotter, T. P.—K4
Coulter, George A. and James Allen—S3
Courant, E. D.—X1
Courant, H.—Z9
Cowan, C. L., Jr., and F. Reines—DA3
Cowan, E. W.—Z2
Danos, M.—H5
Darrow, K. K.—Q4
Dash, J. G.—N1, N5
Davis, H. L. and D. R. Corson—G9
Dayton, I. E. and P. C. Gugelot—T4
De Benedetti, S., M. B. Stearns, M. Stearns, and H. J. Richings—KA8
DeSaussure, G. and L. S. Osborne—G8
Deser, S., W. E. Thirring, and M. L. Goldberger—B8
Dexter, D. L.—M9
Dibeler, Vernon H. and Fred L. Mohler—F11
DiDonato, A. A. MacLeod, and A. C. Webber—M2
Dillon, J. A., Jr., and H. E. Farnsworth—F1
Dorfman, Leon M. and B. A. Hemmer—F10
Dousmanis, G. C.—V7
Dresden, M. and Martin Gutzwiller—B1
Dresner, Joseph—E4
Drost-Hansen, W. and E. J. Workman—M4
Dudziak, Walter F.—G6
Duff, R. E. and H. T. Knight—S12
Duffield, Robert B. and Nathan Sugarman—PB6
Efremov, N.—F5
Eisenstein, Albert S.—QA1
Elliott, L. G., R. L. Graham, J. Walker, and J. L. Wolfson—V10
Fader, W. J. and A. Sperduto—C8
Fermi, Enrico—P1, Q2
Feshbach, Herman—U2
Fivel, Daniel I. and Gilbert N. Plass—E8
Foote, H. L., Jr.—WA3
Forster, H. K. and N. Zuber—F7
Fowler, E. C., H. L. Kraybill, R. M. Walker, and R. S. Preston—WA9
Fraser, J. S. and J. C. D. Milton—Y14
Freistadt, Hans—B10
Fried, Burton D. and R. J. Riddell, Jr.—B5
Friedlander, G., E. Baker, J. Hudis, J. M. Miller, and R. Wolfgang—PB4
Gardner, J. W.—JA7
Gibbons, J. H.—PA1
Gindler, James and Robert B. Duffield—H13
Glassgold, Alfred E.—H4
Glauber, R. J.—E3
Gluckstern, R. L., P. B. Daitch, L. C. Biedenharn and M. M. Hull, Jr.—LA6
Godfrey, T. N. K.—G10
Goldburg, W. I. and R. M. Williamson—C1
Goldman, J. E. and A. Arrott—RA8
Goldwasser and G. Bernardini—G4
Goldwater, D. L. and W. E. Danforth—F9
Gordon, W. L., C. H. Shaw, and J. G. Daunt—N4
Gove, H. E., E. B. Paul, G. A. Bartholomew, and A. E. Litherland—C13
Graham, R. L. and J. Walker—Y3
Grandy, R. A. and A. F. Clark—KA7
Green, D. W., J. N. Cooper, and J. C. Harris—JA9
Green, Melville S.—XA4
Grodzins, L.—H6
Gross, E. P. and M. Krook—QA10
Haberle, W., J. W. Bittner, and R. D. Moffat—LA8
Hagstrum, H. D.—D2
Hartley, R. V. L.—XA1
Havens, W. W., Jr.—WA1
Hayes, W. D.—J2
Henry, Warren E.—RA4
Hensley, E. B.—W2
Herman, R. C., S. Silverman, and R. F. Wallis—E10
Heydenburg, N. P. and G. M. Temmer—C5
Hill, D. A., T. Coor, W. F. Hornyak, L. W. Smith, and G. A. Snow—WA10
Hill, David L. and Kenneth W. Ford—U8
Hill, R. D., E. O. Salant, M. Widgoff, L. S. Osborne, A. Pevsner, D. M. Ritson, J. Crussard, and W. D. Walker—Z10
Hoch, Michael and Herrick L. Johnston—D3
Hofstadter, Robert—O2
Holmgren, H. D., J. M. Blair, B. E. Simmons, and R. V. Stuart—C9
Hornig, D. F.—K3
Hudis, J., R. Wolfgang, N. Sugarman, and G. Friedlander—PB2
Hughes, Vernon W. and Werner B. Teutsch—IA4
Hull, M. H., Jr., L. C. Biedenharn, P. B. Daitch, and R. L. Gluckstern—LA5
Hurlbut, F. C.—F12
Ingersoll, L. R. and D. H. Liebenberg—F8
Innes, Frederick R.—IA3
Jenkins, T. L., D. Luckey, and R. R. Wilson—G5
Jesse, William P. and John Sadauskis—JA10
Joyner, W. T.—PA6
Kaiser, H. F.—LA3
Kalos, M. H. and J. M. Blatt—IA9
Kelly, John, James Ray, and Richard A. Ogg, Jr.—L3
Keuffel, J. W. and L. Mezzetti—Z12
Kies, J. A. and H. L. Smith—I9
Kim, Y. B.—Z8
King, R. W. and D. C. Peaslee—Y13
Kistler, Alan, Vivian O'Brien, and Stanley Corrsin—S6
Kittel, Charles—L9
Knight, Herbert E. and Russell E. Duff—S13
Knowles, J. W.—V11
Kovásznay, Leslie S. G. and Darshan Dosanjh—S14
Kraitchman, J. and B. P. Dailey—V2
Kriessman, C. J. and H. B. Callen—RA3
Kroll, N. M.—B12
Kurşunoğlu, Behram—B7
Lakin, W. and W. Kohn—U6

Lax, M. and R. Toupin—RA1
Leder, Lewis B. and L. Marton—QA8
Lederman, L. M.—A4
Lehovec, Kurt—M7
Leivo, W. and R. Smoluchowski—M10
Lepore, Joseph V., Maurice Neuman, and Richard N. Stuart—U10
Levinger, J. S. and E. G. Grimsal—N7
Li, Yin-Yuan and R. Smoluchowski—E2
Lide, David R., Jr.—V1
Lidofsky, L., R. Gold, and C. S. Wu—R10
Lieberman, D. S., M. S. Wechsler, and T. A. Read—I4
Linsley, John—Z3
Livingston, M. S.—X3
Lomont, J. S.—XA3
Lotspeich, J. F., Ali Javan, and Alfred Engelbrecht—V6
Love, Temple and Fred Maienschein—Y12
Luckey, P. D.—G1
Ludloff, J. F. and M. B. Freidman—J1
Luttinger, J. M.—RA9
MacLeod, A. A., A. R. DiDonato, and A. C. Webber—M1
Maienschein, Fred and Temple Love—R1
Major, J. K. and L. C. Biedenharn—R4
Mandeville, C. E. and Jagdish Varma—R11
Marcus, Paul M.—N3
Marshak, H.—PA3
Martin, R. L.—KA2
Marton, L. and Lewis B. Leder—QA9
Mayburg, Summer—D7
McClure, G. W.—Z7
McGinnis, C. L.—R12
McKelvey, J. P. and R. L. Longini—D6
McLean, E. A. and Waller George—I11
McMaster, W. H. and F. L. Hereford—H1
Meem, J. L.—H11
Melkonian, E. and W. W. Havens, Jr.—WA2
Meshkov, Sydney—IA2
Metzger, F. R. and W. B. Todd—Y8
Mihelich, J. W., Gertrude Scharff-Goldhaber, and Michael McKeown—Y5
Mingins, Charles R., Robert W. Perry, and Albert D. Frost—M5
Minton, George H.—H7
Mizushima, Masataka—V8
Murray, B. B. and J. D. Kurbatov—R9
Murray, P. C., R. I. Scace, R. O. Haxby, and T. R. Palfrey, Jr.—JA5
Nagamatsu, H. T.—J3
Naumann, R. A.—Y6
Neufeld, Jacob—XA2
Newman, E. and W. L. Alford—C4
Newson, H. W., R. M. Williamson, A. L. Toller, and P. F. Nichols—PA5
Newton, Roger G.—U9
Nicolai, V. O. and E. L. Goldwasser—G2
Nowick, A. S.—I8
Nozick, Seymour—QA12
Ogg, Richard A., Jr.—L2
Oriani, R. A.—I5
Overhauser, A. W.—L8
Pai, Shih I.—S2
Palmatier, E. D., J. T. Meers, and C. M. Askey—KA10
Parzen, Philip—XA8
Patterson, J. R., H. W. Newsom, R. C. Mobley, and T. E. Gilmer——PA4
Paul, E. B., H. E. Gove, G. A. Bartholomew, and A. E. Litherland—C14
Pearson, G. L., W. T. Read, Jr., and F. J. Morin—D4
Pegram, G. B.—Q1
Penning, J. R. and F. H. Schmidt—R3
Percus, Jerome J. and George J. Yevick—U5
Pevsner, Aihud, James Rainwater, Ross Williams, and Seymour J. Lindenbaum—KA1
Philipp, H. R.—QA6
Piper, William W. and Ferd E. Williams—QA4
Powell, W. M.—T12
Pomerantz, W. A.—Z1
Pond, T. A.—H8
Rabi, I. I.—Q3
Rainwater, James—O3
Ramsey, N. F.—DA1
Read, T. A., M. S. Wechsler, and D. S. Lieberman—I3
Reynolds, George T. and S. B. Treiman—Z11
Riddell, R. J., Jr., and Burton D. Fried—B4
Rittner, E. S.—W3
Roberts, A. and J. Tinlot—KA4
Roesch, William C.—R2
Ross, Donald—S5
Rothman, M. A., H. S. Hans, and C. E. Mandeville—WA5
Rothstein, Jerome—XA5
Ruderman, M. A. and H. Brown—B9
Rustad, B. M.—DA4
Sagane, Ryokichi and Walter F. Dudziak—G3
Sakai, M., J. Dick, and J. D. Kurbatov—R7
Salkovitz, Edward I. and Paul L. Smith—M6
Saraf, Babulal—Y1
Schensted, Craige—XA7
Scherrer, V. E., B. A. Allison, and W. R. Faust—WA7
Schneider, E. E.—L7
Schriever, Barbara Dwight, E. A. Whalin, and A. O. Hanson—JA4
Schwartz, Robert N.—XA10
Scott, M. B., A. O. Hanson, and D. W. Kerst—JA2
Serber, R. L.—A3
Sessler, A. M. and H. M. Foley—IA5
Severiens, J. C. and C. S. Fuller—D5
Sharp, W. T., H. Gellman, and G. E. Tauber—IA7
Shatas, R. A., J. F. Marshall, and M. A. Pomerantz—H2
Sheer, C., A. Zinn and N. Hartmann—LA10
Sherwood, J. E., T. E. Stephenson, C. P. Stanford, and Seymour Bernstein—WA8
Shutt, R. P.—A2
Shuttleworth, R. A. and B. C. Bradshaw—F3
Silver, E. G. and R. W. Waniek—LA9
Singer, S. E., W. S. Emmerich, and J. D. Kurbatov—R6
Smith, B. and H. A. Boorse—N6
Smith, H. L. and J. A. Kies—I10
Smith, J. A., J. N. Cooper, and J. C. Harris—C12
Snow, G. A., T. Coor, D. A. Hill, W. F. Hornyak, and L. W. Smith—WA11
Snowdon, S. C. and W. D. Whitehead—T9
Snyder, W. S. and Jacob Neufeld—I6
Solimene, N. and B. P. Dailey—V3
Spetner, L. M.—QA13
Spielberg, N., C. H. Shaw, and J. A. Soules—E6
Sproull, R. L.—W1
Spry, W.—KA6
Stearns, M., M. B. Stearns, S. De Benedetti, and L. Leipuner—KA9
Stewart, J. W. and C. A. Swenson—N9
Strauch, K. and F. Titus—T6
Sugarman, Nathan and Anthony Turkevich—PB5
Sugarman, R. and S. De Benedetti—Z6
Swann, C. P.—LA1
Tauber, G. E. and Ta-You Wu—IA8
Taylor, T. B.—T8
Temmer, G. M. and N. P. Heydenburg—C2
Templeton, D. H. and E. M. Douthett—H12
Tinlot, J. and A. Roberts—KA5
Titus, F. and K. Strauch—T5
Tobocman, W.—IA10
Tomlinson, E. P., R. A. Naumann, and J. W. Mihelich—V7
Toupin, R. and M. Lax—RA2
Townes, C. H.—O4
Trumble, R. E., Jr.—C6
Turkevich, Anthony—PB1
Uberoi, M. S.—J4
Ufford, C. W. and S. Meshkov—IA1
Van der Ziel, A.—W4
Varma, Jagdish—Y9
Venable, Douglas and Leo F. Perry—S11
Vineyard, G. H.—E1
Vogt, Erich and Gregory H. Wannier—XA9
von Krzywoblocki, M. Z.—S4
Wall, N. S.—JA3
Wall, C. N.—P2
Wallenmeyer, W.—LA2
Wallis, G. and H. E. Farnsworth—QA7
Walsh, J. M.—K1
Wang, T. C. and C. H. Townes—L5
Watson, W. R., J. J. Dropkin, and A. T. Halpin—QA3
Webb, W., J. W. Spencer, and R. W. Schiessler—F4
Weber, J.—XA6
Wechsler, M. S., D. S. Lieberman, and T. A. Read—I2
Wegel, R. L. and H. C. Rorden—S1
Weinstein, Roy, Martin Deutsch, and Sanborn Brown—H9
Whalin, E. A. and R. A. Reitz—E7
Wheeler, J. A.—P3
White, M. G.—X4
White, Robert L.—V4

Wilkinson, M. K., C. G. Shull, L. D. Roberts, and S. Bernstein—N8
Willard, H. B., J. K. Bair, and J. D. Kington—T10
Williams, R. W. and J. H. Vilain—G11
Williams, Ross, Aihud Pebsner, James Rainwater, and Seymour J. Lindenbaum—KA3
Willig, F. J.—K2
Winkler, Stanley—QA11
Witmer, Enos E.—JA6
Wolfe, B., J. W. DeWire, and A. Silverman—G7
Wolfenstein, L.—U1
Wolff, G.—QA5
——, P. H. Keck, and J. D. Broder—F6
Wolff, P. A.—D1
Wolfgang, R. and G. Friedlander—PB3
Wood, R. E.—Y4
Woodruff, Robert W. and M. Parker Givens—E5
Workman, E. J. and W. Drost-Hansen—M3
Yevick, George J. and Jerome J. Percus—U4
Zacharias, J. R.—DA2
Zemach, A. C. and R. J. Glauber—WA4
Zimmerman, S. F., Jr., and C. P. Browne—C11
Zucker, A. and H. L. Reynolds—C10
Zumino, Bruno—B11

PLAN OF BUILDINGS AND GROUNDS, COLUMBIA UNIVERSITY



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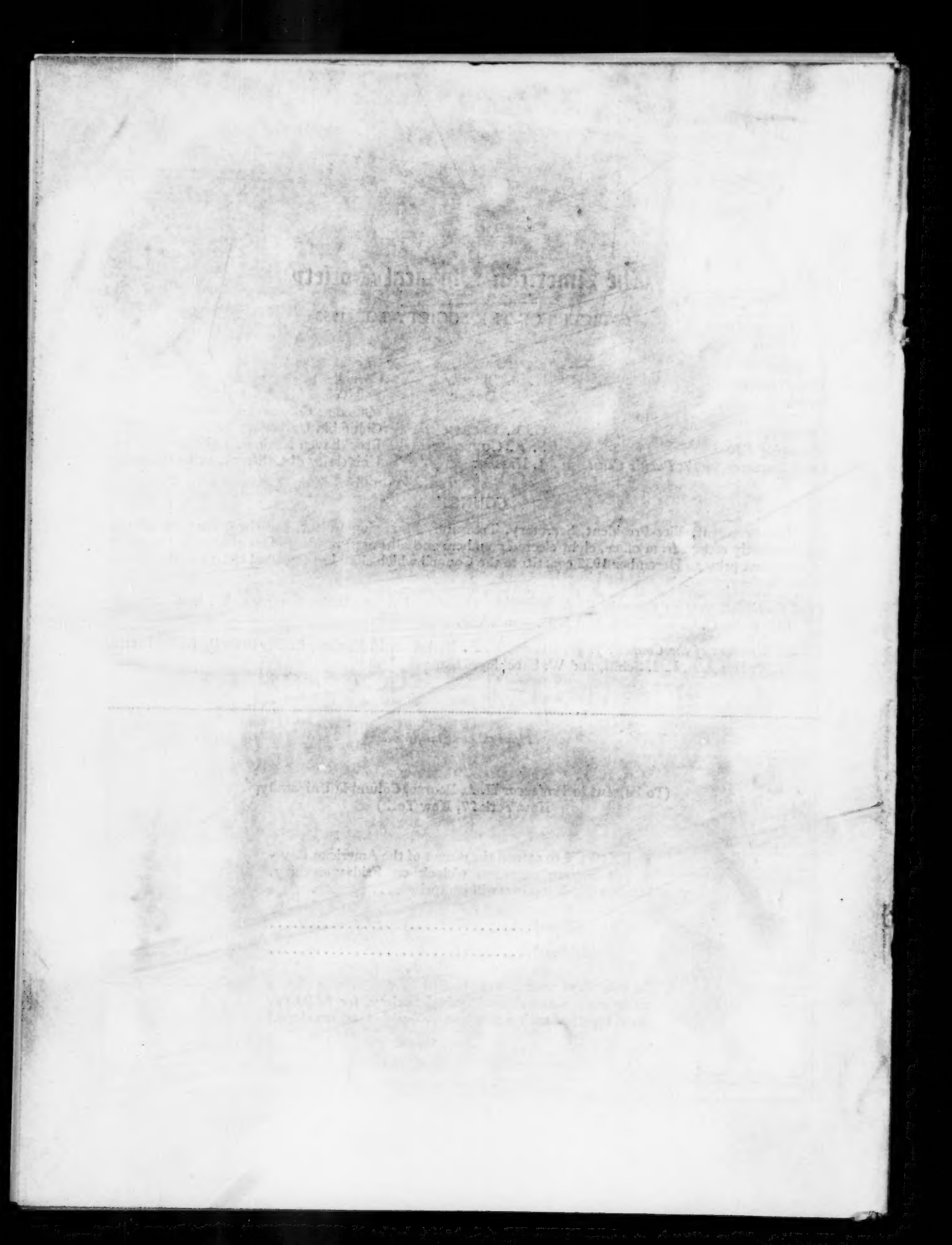
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